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SEEDLING REACTIONS OF WHEAT VARIETIES TO STEM RUST AND LEAF RUST AND OF OAT VARIETIES TO STEM RUST AND CROWN RUST[1]

BY MARGARET NEWTON[2], T. JOHNSON[3], AND B. PETURSON[4]

Abstract

A study of the rust reactions of wheat varieties to 20 physiologic races of stem rust has shown that several varieties of the *vulgare* type, namely, McMurachy, Eureka, and several strains from Kenya, East Africa, are immune in the seedling stage at ordinary greenhouse temperatures (55° F. to 80° F. daily). This immunity largely disappears when the plants are kept at a constant high temperature (75° F. to 80° F.). Certain other varieties and hybrid strains were found rather highly resistant to eight physiologic races of leaf rust, but none of the *vulgare* varieties tested showed immunity or high resistance to both stem rust and leaf rust.

Tests to determine the resistance of oat varieties to the physiologic races of oat stem rust and crown rust prevalent in Canada showed that four oat varieties derived from the cross Hajira × Joanette were resistant to all the physiologic races of oat stem rust used in the test, and that certain strains derived from the cross Victoria × (Hajira × Banner Sel. 524) were resistant to all but one of these races. The last mentioned strains and the varieties Victoria and Trispernia proved resistant to the nine races of crown rust to which they were tested.

Introduction

The work reported in the present paper was undertaken mainly to assist the plant breeders of the Dominion Rust Research Laboratory and other Canadian plant geneticists in their plant breeding projects. There were two ways in which this could be done: first, by testing the rust resistance of varieties from various sources in the hope of discovering suitable breeding material; second, by determining the relative rust resistance of different lines of the hybrid populations developed by the plant breeders.

Although varieties are ultimately selected for rust resistance on the basis of their reaction to rust in the field, it is nevertheless important to supplement field work with studies conducted in the greenhouse where each variety can be studied in the seedling stage for its reaction to the various physiologic races of a rust. Reactions of varieties in the seedling stage to rust may be determined quickly and accurately, and because varieties found resistant

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to a physiologic race in the seedling stage are also resistant to it in the adult stage it is often possible, by means of such tests, to predict the field reaction of a variety with considerable accuracy.

This method of determining rust resistance appears to be fully satisfactory for oats but has its limitations in tests with wheat varieties because the seedling and adult plants of many wheat varieties do not react identically to stem rust, a fact noted by several earlier investigators including Melchers and Parker (12), Harrington and Aamodt (5), Hursh (8), Hayes, Stakman, and Aamodt (6), and Aamodt (1). A similar difference between the reactions of the seedling and adult plants of some wheat varieties to leaf rust was noted by Johnston and Melchers (9) who found that rust resistance increased as the plants advanced towards maturity. Such discrepancy between seedling and mature-plant tests is exemplified by the stem-rust reactions of many hybrid strains derived from crosses of common wheats with Hope and H 44. These strains, though completely or moderately susceptible in the seedling stage are highly resistant in later stages of growth. They possess what has been described by Goulden, Neatby and Welsh (4) as "mature-plant resistance".

Owing to the fact that the plant breeding program in connection with which this work was undertaken includes the development of wheat varieties resistant to wheat stem rust and leaf rust, and oat varieties resistant to oat stem rust and crown rust, it was found necessary to work with all these rusts. As it was not possible to include in these tests all of the physiologic races of these rusts occurring in Canada, the tests were necessarily confined to certain selected races. In the selection of these races two criteria were kept in mind: first, to include all of the races most prevalent in Canada in the last few years, and second, to include races of diverse pathogenic characteristics. The twenty selected races of wheat stem rust (*Puccinia graminis Tritici* Erikss. and Henn.) therefore included races such as 11, 17, 19, 21, 29, 32, 34, 36, 38, 39, and 56, which have been collected frequently in the field (16), and races such as 9, 15, and 120, which have seldom been collected but possess a wide pathogenic range. The tests with wheat stem rust may be regarded as a continuation of similar work reported in previous papers (17, 18). The present tests, however, include a number of varieties that have been produced since the time of the earlier work as well as several physiologic races of stem rust not known at that time, including race 56 which has in recent years become the predominant race in Canada and the United States.

Most of the varieties subjected to these tests were also tested for their reaction to eight physiologic races of leaf rust of wheat (*Puccinia triticina* Erikss.) including some of the races most prevalent in Canada, such as races 1, 9, 52, and 76. The fact that the same varieties were tested for their reaction to physiologic races of both stem rust and leaf rust makes it possible to select varieties on the basis of their resistance to both rusts.

The infection tests with oat varieties included all the known races of oat stem rust (*Puccinia graminis Avenae* Erikss. and Henn.) with the exception

of race 9 which has only been collected once in Canada, and race 11 which is a European race resembling race 10*a* rather closely. A number of the varieties tested have been previously studied for their seedling reactions to 10 physiologic races by Levine and Smith (10). The present tests embrace, however, many varieties not tested by them including several recently developed in Canada. Most of these varieties were also tested for their reaction to nine physiologic races of crown rust (*Puccinia coronata Avenae* Erikss. and Henn.). These races include all the ones commonly prevalent in Canada (16, 19) as well as race 45, which has been collected only twice in Canada but which is pathogenic to the variety Bond now widely used in breeding on account of its high resistance to most other crown rust races.

Methods

In all the varieties tested, the plants were grown in 4-in. pots, about ten seedlings per pot. The first seedling leaf of each plant was inoculated when 3 to 4 in. high. Following inoculation, the plants were kept in moist chambers for 24 hr., after which they were placed on benches in the greenhouse where they remained until notes were taken on their rust reactions. Two pots of seedlings were used for each inoculation so that the reactions of about twenty seedlings were obtained for each physiologic race employed. When the reaction of a variety to any race was in doubt, the whole test was repeated. The reactions were recorded in terms of the system originally devised by Stakman and Levine (20) and modifications of it were used for the other rusts (2, 7, 11, 13, 21, 22).

Owing to the fact that this method of recording rust reactions involves the use of symbols not familiar to all plant breeders, it was decided to translate these into terms of resistance and susceptibility so that the relative resistance of the varieties might be grasped more readily. This has been accomplished by means of the following scale in which a valuation in terms of rust resistance is given to the various symbols used for recording the infection types:

Symbol for infection type	Valuation in terms of rust resistance	Abbreviation
0 and 0;	= immunity	I
1, 2, 2+, x=, x−	= high resistance	R
2++, 3=, x	= moderate resistance	MR
3−, 3, x+, x++	= moderate susceptibility	MS
3+, 3++, 4	= complete susceptibility	S

It should be stated that the divisions between the different classes in the above scale are quite arbitrary. The justification of this procedure is that it facilitates a comparison of the relative resistance of two or more varieties. For the sake of convenience, the abbreviations shown above have been used in tabulating the rust reactions of the different wheat and oat varieties.

The Reaction of Wheat Varieties in the Seedling Stage to Physiologic Races of Stem Rust and of Leaf Rust

Stem Rust

Included in the tests of the reaction of wheat varieties to races of stem rust and leaf rust are some of the more promising of the rust-resistant wheats developed in recent years such as the stem-rust resistant varieties and strains developed in Canada from crosses of Marquis and Reward with Hope and H 44, and the Australian variety Eureka which was produced by Mr. S. L. Macindoe from the cross (Kenya Crossbred C 6040 × Florence) F_1 × Dundee and which has shown high stem-rust resistance in Australia. In addition, a number of varieties were tested that have no commercial value but that may possibly serve as useful breeding material, such as *Triticum Timopheevi* Zhuk. McMurachy*, and several strains developed in Kenya, East Africa.†

Among varieties known to possess some resistance to leaf rust may be mentioned a group of spring wheats supplied to the Dominion Rust Research Laboratory by Dr. R. M. Caldwell, Purdue University, Indiana. These wheats include Illinois No. 1 B. 8 and certain derivatives of the crosses Warden C.I. 4994-4 × Hybrid English W. 325, Chinese C.I. 6223 × Progress C.I. 6902, and Chinese C.I. 6223 × Emmer S.D. 293.

For purposes of comparison, tests were also made with a number of the older varieties such as Marquis, Huron, Preston, and Garnet, as well as the winter wheats Democrat, Hussar, Mediterranean, Malakoff, Fultz, and Kawvale.

The seedling reactions to stem rust and leaf rust are recorded in Tables I and II respectively. The varieties have been grouped according to the species to which they belong, but, within each species group, the varieties are arranged in approximately the order of their resistance—the most resistant varieties being placed first and the most susceptible last.

The tests with physiologic races of stem rust showed that, in the *vulgare* group, Eureka, the Kenya strains, and McMurachy are immune to all the races used, at least when tested in the seedling stage at ordinary greenhouse temperatures. A striking feature of the rust reaction of these varieties is the fact that this immunity disappears at high temperatures. The Kenya strains and McMurachy, when tested at ordinary greenhouse temperatures (varying from about 55° F. at night to 80° F. by day), developed, at most, minute flecks indicative of extreme resistance. When tested with the same race at a constant temperature of 75° to 80° F. they showed moderate or even complete susceptibility. Similar results were shown by plants approaching the boot stage of growth.

* *McMurachy was selected from a field of Garnet wheat, about 1930, by Mr. M. S. J. McMurachy of Strathclair, Manitoba. It was found to be resistant to stem rust and was brought to the attention of the plant breeders at the Dominion Rust Research Laboratory in 1935.*

† *The Kenya varieties were originally developed at Njoro, Kenya Colony, and were obtained by the Dominion Rust Research Laboratory in 1934. The identification numbers they bore at that time and the accession numbers given them at the Rust Research Laboratory were as follows: 122 D.I.T. (L)—R.L. 1373; 117 E.16.B.1—R.L. 1374; 117 B.5.B.2. (L)—R.L. 1375; 117 K.16.A(L)—R.L. 1376; 117 I.5.F. (L)—R.L. 1377.*

TABLE I

SEEDLING REACTIONS OF 78 WHEAT VARIETIES AND HYBRID STRAINS TO 20 PHYSIOLOGIC RACES OF *Puccinia graminis Tritici*

Variety	C.I. No.	R.L. No.	Physiologic race																			
			9	10	11	15	17	19	21	29	32	34	36	38	39	48	50	56	113	120	139	152
Triticum vulgare																						
Eureka		1534	–	I	I	I	I	I	I	I	I	I	I	I	I	I	–	I	I	I	I	I
Kenya		1373	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
Kenya		1374	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
Kenya		1375	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
Kenya		1376	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
Kenya		1377	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
McMurachy		1313	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
Thatcher		1246	I	MS	MS	MR	I	I	I	I	I	MR	MR	MS	MS	I	I	MR	MR	I	I	R
Apex		1320	I	MR	MR	MS	I	I	I	I	MS	S	MS	MS	MS	I	I	MS	MR	I	I	MR
Canus		1321	–	R	S	S	I	I	I	I	S	S	S	R	R	R	–	S	S	I	I	R
Hope × Reward		1165	MS	R	MS	MS	MR	R	MS	MS	MS	MS	R	R	R	R	R	R	MR	MR	R	R
Hope		209	MS	R	MS	MS	MS	R	S	MS	MS	S	R	R	R	R	I	R	R	MR	R	R
H 44-24		229	MS	R	MR	MS	MS	R	MS	MS	MS	MS	R	R	R	MS	R	R	R	MR	R	R
Marquillo		132	MS	R	R	MS	MS	R	R	I	MS	MS	MS	R	MR	R	S	R	R	MR	MS	R
Renown Selection		716.6	MS	R	MS	S	MS	R	MS	MS	MS	S	R	R	R	R	R	R	R	R	R	R
Regent		975.1	MS	R	MS	MS	MS	R	MS	MS	MS	S	R	R	R	R	R	R	R	MS	R	R
Renown		716	MR	MR	MR	MS	MR	R	MS	MR	MS	MS	MR	R	R	MR	MS	MS	R	R	MR	R
Marquis × (H 44-24 × Marquis)		1333	MS	R	S	S	MS	R	S	S	MS	MS	R	R	R	R	R	R	MR	R	R	R
Reliance	7370	1813	I	S	S	S	I	I	I	I	S	S	S	S	MS	I	I	S	MR	I	R	MS
Coronation		729A	MS	R	S	MS	MS	R	S	S	MR	S	MR	R	R	R	R	MR	MR	R	R	R
H 44-24 × Reward		967	MR	MR	MR	MS	R	R	MR	MS	MS	MS	MR	MR	MR	MR	MS	MS	R	MR	MS	MR
H 44-24 × Marquis		1081	MS	MR	MS	MS	MS	R	MS	S	MS	MS	MS	MR	R	R	MR	R	MR	MR	MR	R
Marquis × (Pentad × Marquis)		1326	MS	R	S	S	MS	R	MS	S	MS	S	MS	R	R	R	R	S	MR	MR	R	R
H 44-24 × Reward		1097	MR	MR	MS	MS	MR	R	MS	MS	MR	S	S	MR	MR	MR	MS	MS	R	MR	MR	MR
H 44-24 × Marquis		704.1	MR	R	MS	MS	MR	R	MS	MS	MS	MS	MS	MR	MR	MR	MS	S	MR	MR	MS	MR
Webster	3780	365	MS	MR	MR	MS	MR	MS	MS	MS	MS	MS	MS	MR	MR	MS	MS	MR	R	MR	MR	MR
Haynes' Blue Stem		200	MS	R	S	S	MS	R	S	S	S	S	S	R	R	R	MR	S	R	R	MS	R
Marquis		572	S	R	S	S	S	R	S	S	S	S	S	R	R	R	R	S	MR	MR	R	R

TABLE I—*Continued*

SEEDLING REACTIONS OF 78 WHEAT VARIETIES AND HYBRID STRAINS TO 20 PHYSIOLOGIC RACES OF *Puccinia graminis Tritici*—*Continued*

Variety	C.I. No.	R.L. No.	Physiologic race																			
			9	10	11	15	17	19	21	29	32	34	36	38	39	48	50	56	113	120	139	152
Triticum vulgare—concluded																						
Red Bobs		134	MS	R	S	S	S	R	S	S	S	S	S	R	R	R	MS	S	R	R	MS	R
Red Fife		65	MS	R	S	S	S	R	S	S	S	S	S	R	R	R	MS	S	R	R	MS	R
Ceres		127	S	MR	MS	MS	S	MS	S	S	MR	MS	S	MS	MR	I	MS	S	MR	R	MS	I
Early Triumph		94	–	R	S	S	S	R	S	S	S	S	S	R	R	R	–	S	R	MS	MS	R
Huron		20	MS	R	S	S	S	R	S	S	S	S	S	R	MS	R	MS	S	R	R	S	R
Preston		207	S	R	S	S	S	R	S	S	S	S	S	MR	R	R	MS	S	R	R	S	R
Kota	5878	571	S	R	S	S	S	MS	S	MS	S	S	S	MS	MS	R	R	S	MS	MR	R	I
Malakof	4898	1538	MR	MS	MR	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
Kawvale		1451	–	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	–	MS	MS	MS	MS	MS
Loros	3779	1891	MS	MR	S	S	MS	I	S	S	MR	S	MS	MR	MR	S	S	S	MR	MS	MS	MS
Norka	4377	1888	MS	S	MR	R	S	MS	MR	R	S	R	R	S	S	MS	S	MS	S	S	S	MS
Warden × Hybrid		1803	–	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	–	MS	MS	MS	MS	MS
Glenwood		1411	S	S	S	S	S	S	S	S	R	S	S	MS	MS	I	MS	S	MS	R	MS	I
Hard Federation		1887	MS	R	S	S	S	MR	S	S	S	S	S	MR	MR	MR	S	S	MR	MR	S	R
Reward		79	S	MS	S	S	S	R	S	S	S	S	S	R	R	MR	MR	S	MR	S	MS	MR
Renfrew		135	S	MR	S	S	S	R	S	S	S	S	S	MR	MR	MR	–	S	S	MS	MS	R
Illinois No. 1.B. 8		1593	–	MS	S	S	S	MS	S	S	S	S	S	S	MS	MS	–	S	S	S	S	I
Carina	3756	1889	MS	MR	S	S	S	I	S	S	S	S	S	MR	MR	S	S	S	MR	S	S	S
Brevit	3778	1890	S	MR	S	S	S	MR	S	S	S	S	S	MR	MR	S	S	S	MR	S	S	S
Ridit		1932	–	MS	S	S	S	MS	S	S	S	S	S	MS	MS	MS	–	S	S	S	MS	MS
Hard Red Calcutta		1893	S	S	S	S	S	S	S	S	S	S	S	S	S	MS	S	S	S	S	S	S
Chinese × Emmer		1802	–	S	S	S	S	S	S	S	S	S	S	S	S	S	–	S	S	S	S	S
Chinese × Progress		1804	–	S	S	S	S	S	S	S	S	S	S	S	S	S	–	S	S	S	S	S
Chinese × Progress		1805	–	S	S	S	S	S	S	S	S	S	S	S	S	S	–	S	S	S	S	S
Democrat	3384	1535	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Fultz		1539	–	S	S	S	S	S	S	S	S	S	S	S	S	S	–	S	S	S	S	S
Fultz Selection		1540	–	S	S	S	S	S	S	S	S	S	S	S	S	S	–	S	S	S	S	S
Garnet		15	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Hussar	4843	1892	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Mediterranean	3332	1537	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Prelude		25	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

TABLE I—*Concluded*

SEEDLING REACTIONS OF 78 WHEAT VARIETIES AND HYBRID STRAINS TO 20 PHYSIOLOGIC RACES OF *Puccinia graminis Tritici*—*Concluded*

Variety	C.I. No.	R.L. No.	Physiologic race																			
			9	10	11	15	17	19	21	29	32	34	36	38	39	48	50	56	113	120	139	152
Triticum durum																						
Iumillo		7	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
Iumillo × Mindum		1183	–	I	I	I	I	I	I	I	I	I	I	I	I	R	–	I	R	I	I	R
Belaturka		1412	–	R	R	R	R	R	R	R	MR	R	R	R	R	MR	–	R	R	R	MR	R
Pentad		203	MS	MS	R	R	MS	MS	MS	R	I	MR	R	R	MS	I	R	R	R	MR	I	I
Mindum	5296	568	S	S	S	S	S	S	S	MR	MR	S	R	MR	S	R	I	R	R	S	R	I
Spelmar	6236	569	S	S	S	S	S	S	S	MR	MR	S	R	MR	S	R	I	R	R	S	R	I
Tibet		1396	–	MS	MS	MS	MR	R	R	MR	S	MS	MR	MS	MR	MR	–	MS	R	R	S	MS
Akrona		1252	–	S	S	S	S	S	S	MR	MR	S	R	MR	S	MR	–	R	R	MR	R	R
Arnautka	4064	570	S	S	S	S	S	S	S	MS	MS	S	R	MS	S	MS	R	R	MS	S	R	R
Kubanka	2094	565	S	S	S	S	S	S	S	MR	R	S	MR	MS	S	MS	R	S	R	S	MR	R
Acme	5284	566	S	S	S	S	S	S	S	MS	MS	S	S	MS	S	S	MS	S	S	S	S	S
Pelissier		145	S	S	S	S	S	S	S	S	S	S	S	S	S	S	–	S	S	S	S	S
Triticum compactum																						
Jenkin	5177	1814	S	S	MS	S	MS	S	MS	S	MS	S	MS	S	S	S	MS	MS	S	S	MS	S
Little Club	4066	223	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Triticum dicoccum																						
Khapli	4013	563	R	R	R	R	R	R	R	R	R	R	R	R	R	R	I	R	R	R	I	R
Vernal	3686	567	S	R	R	S	R	I	I	R	R	I	I	R	R	R	I	R	I	MS	R	I
Black Persian		388	R	MR	R	R	R	R	R	R	R	R	R	R	MR	R	R	MR	MR	R	MR	R
Triticum monococcum																						
Einkorn	2433	227	S	S	MS	S	MS	MS	R	MS	MS	R	S	S	S	S	I	R	S	S	R	S
																					R	S
Triticum Timopheevi		1308	I	I	I	R	I	MR	R	I	I	I	R	R	I	R	I	MR	I	I	I	I

TABLE II

SEEDLING REACTIONS OF 75 WHEAT VARIETIES AND HYBRID STRAINS TO 8 PHYSIOLOGIC RACES OF *Puccinia triticina*

Varieties	C.I. No.	R.L. No.	Physiologic race							
			1	9	11	27	28	29	52	76
Triticum vulgare										
Warden × Hybrid English W 325		1803	R	I	R	R	R	I	R	R
Carina	3756	1889	I	R	R	R	R	MR	I	MR
Illinois No. 1.B 8	11628	1593	R	R	R	R	R	R	R	R
Kawvale	8180	1451	I	I	R	I	S	I	I	S
Fultz		1539	I	I	R	I	S	I	I	S
Chinese × Progress		1805	R	R	R	MR	R	MR	R	R
Fultz Selection		1540	I	I	R	I	S	R	I	S
Chinese × Progress		1804	R	R	R	MR	MR	MR	R	R
Chinese × Emmer S.D. 293		1802	R	R	MR	MR	MR	R	R	MS
Brevit	3778	1890	I	R	S	R	R	MR	R	S
Webster	3780	365	I	S	R	S	R	MR	I	MR
Hussar	4843	1892	R	R	R	MR	MS	MS	MS	R
Marquis × (H 44-24 × Marquis)		1333	MR	MR	MR	MR	R	MR	MR	MR
Hope		209	MR	MR	MR	MR	R	MR	MR	MR
Democrat	3384	1535	I	R	R	R	S	R	S	S
Hope × Reward		1165	MR	MR	MR	MR	MR	MR	MR	MR
H 44-24		229	MR	MR	MR	MR	MR	MR	MR	MR
Renown Selection		716.6	MR	MR	MR	MS	R	MR	MR	MR
Mediterranean	3332	1537	R	R	R	R	S	R	S	S
Coronation		729A	MR	MS	MR	MR	MR	MR	MR	MR
H 44-24 × Marquis		704.1	MR	MR	MR	MR	MR	MR	MR	MS
Renown		716	MR	R	MS	MR	MS	MR	MR	MR
Hard Federation		1887	MS	MR	S	MR	MR	R	R	MS
Malakof	4898	1538	I	S	I	S	S	S	S	I
Norka	4377	1888	I	S	I	S	S	S	S	I
Marquis × (Pentad × Marquis)		1326	MS	MR	MS	MR	MS	MR	MS	MR
Loros	3779	1891	I	S	S	MS	MS	S	R	S
H 44-24 × Marquis		1081	MS	MS	MR	MS	MS	MS	MS	MS
H 44 × Reward		975	MS	MS	MS	MS	MS	MS	MS	MS
H 44-24 × Reward		967	MS	S	MS	S	S	S	MS	MS
Reliance	7370	1813	S	S	MS	S	S	S	MS	MS
Haynes' Blue Stem		200	S	S	S	S	S	MS	MS	S
Glenwood		1411	S	S	MS	S	S	S	S	MS
Regent		975.1	S	S	S	MS	S	MS	S	S
Kenya		1376	S	S	S	S	MS	S	MS	S
Kenya		1375	S	S	S	S	MS	S	S	S
Preston		207	S	S	S	S	S	S	MS	S
Renfrew		135	S	S	S	S	S	S	MS	S
Apex		1320	S	S	S	S	S	S	S	S
Canus		1321	S	S	S	S	S	S	S	S
Ceres		127	S	S	S	S	S	S	S	S
Early Triumph		94	S	S	S	S	S	S	S	S
Garnet		15	S	S	S	S	S	S	S	S
Huron		20	S	S	S	S	S	S	S	S
Kenya		1373	S	S	S	S	S	S	S	S
Kenya		1374	S	S	S	S	S	S	S	S
Kenya		1377	S	S	S	S	S	S	S	S
Kota	5878	571	S	S	S	S	S	S	S	S
Marquillo		132	S	S	S	S	S	S	S	S
Marquis		572	S	S	S	S	S	S	S	S

TABLE II—*Concluded*

SEEDLING REACTIONS OF 75 WHEAT VARIETIES AND HYBRID STRAINS TO 8 PHYSIOLOGIC RACES OF *Puccinia triticina*—*Concluded*

Varieties	C.I. No.	R.L. No.	Physiologic race							
			1	9	11	27	28	29	52	76
Triticum vulgare—continued										
McMurachy		1313	S	S	S	S	S	S	S	S
Prelude		25	S	S	S	S	S	S	S	S
Red Bobs		134	S	S	S	S	S	S	S	S
Red Fife		65	S	S	S	S	S	S	S	S
Reward		79	S	S	S	S	S	S	S	S
H 44-24 × Reward		1097	S	S	S	S	S	S	S	S
Thatcher		1246	S	S	S	S	S	S	S	S
Triticum compactum										
Little Club	4066	223	S	S	S	S	S	S	S	S
Triticum durum										
Arnautka	4064	570	R	R	MR	R	R	R	R	R
Iumillo		7	R	R	MR	R	MS	R	R	R
Mindum	5296	568	MS	R	MR	R	R	R	R	R
Akrona		1252	MR	R	MS	R	MR	R	R	R
Iumillo × Mindum		1183	MS	R	S	R	R	MR	R	MR
Acme	5284	566	S	R	MR	R	MS	R	MS	MS
Spelmar	6236	569	S	R	S	R	MS	R	MR	MS
Pelissier		145	MR	MR	MS	R	S	MS	MR	MS
Pentad		203	MS	MR	MS	MR	MS	MR	MR	MS
Tibet		1396	MS	MR	S	MR	S	R	MS	MS
Belaturka		1412	MS	MR	S	MR	S	MR	MR	S
Kubanka	2094	565	S	MS	S	MR	S	R	MS	S
Triticum dicoccum										
Khapli	4013	563	MS	MR	MS	R	MR	MS	MS	MS
Vernal	3686	567	MS	MR	S	MS	MS	MS	MS	MS
Black Persian		388	S	S	R	S	MS	S	S	S
Triticum monococcum										
Einkorn	2433	227	R	I	R	R	R	R	R	R
Triticum Timopheevi		1308	I	I	I	I	I	I	I	I

Thatcher, Apex, and many of the varieties derived from crosses of common wheats with Hope and H 44, show a considerable amount of resistance to stem rust. It should be pointed out here that the seedling tests are not a fair indication of the rust reaction of Hope and H 44 derivatives, as these, in later stages of growth, develop the so-called mature-plant resistance. The field resistance of these varieties is, therefore, greater than that indicated by the seedling tests. This resistance cannot, however, be regarded as completely stable inasmuch as recent tests with Hope wheat have shown that adult plants kept at a constant high temperature (75° to 80° F.) are rendered moderately susceptible.

Among the non-*vulgare* varieties, only Iumillo and Iumillo × Mindum showed immunity. It should be noted, however, that when Iumillo was tested at constant high temperatures (75° to 80° F.) immunity was occasionally altered to moderate resistance (an "x" reaction). Several other varieties such as Pentad, Belaturka, Khapli, Black Persian, and *T. Timopheevi* were highly resistant at ordinary greenhouse temperatures.

Leaf Rust

In the tests with leaf rust of wheat, considerable resistance was shown by Illinois No. 1 B. 8 and certain derivatives of the crosses Warden × Hybrid English, Chinese × Progress, and Chinese × Emmer. These results were supported by evidence secured from adult plants of the same varieties subjected to a rather severe artificially induced epidemic in the field during the summer of 1939. They were found to have considerably more resistance to leaf rust than the varieties Fultz and Kawvale, which are generally regarded as at least moderately resistant (3, 9, 24). Besides, in the greenhouse tests, Fultz and Kawvale proved completely susceptible to two of the physiologic races. A moderate resistance was shown by several other varieties, such as Carina, Brevit, Webster, Hope, H 44, and a number of derivatives of crosses with the two last-mentioned varieties. Varieties descended from Hope and H 44, however, are, in the later stages of growth, somewhat more resistant to leaf rust, so that the seedling reaction is not an exact indication of the field reaction. The variety McMurachy and the Kenya strains which proved immune to stem rust are susceptible to leaf rust. Of the varieties tested, the ones showing the greatest resistance to both stem rust and leaf rust appear to be *Triticum Timopheevi* and the *durum* variety Iumillo.

The Reaction of Oat Varieties in the Seedling Stage to Physiologic Races of Oat Stem Rust and of Crown Rust

Stem Rust

The oat varieties studied for their reaction to physiologic races of oat stem rust included many new varieties developed in recent years in Canada and the United States. The rust reactions of these varieties are recorded in Table III. On the basis of these reactions, the varieties are divided into the following six groups:

(1) A group consisting of several strains derived from the cross Hajira × Joanette. These strains are resistant or moderately resistant to all the 11 physiologic races used in these tests.

(2) A group comprising strains derived from the crosses Hajira × Banner and Victoria × (Hajira × Banner Sel. 524), which show resistance to all races except race 6. These together with those of the first group were developed by Mr. J. N. Welsh of the Dominion Rust Research Laboratory.

(3) Varieties reacting like Richland, and including Monarch Selection, Hajira, Rusota, Iogold, Vanguard, Green Russian N.D. 22005, and several strains derived from the cross Victoria × (Hajira × Banner Sel. 524). These are resistant to races 1, 2, 3, 5, 7, and 12.

TABLE III

SEEDLING REACTIONS OF 78 OAT VARIETIES AND HYBRID STRAINS TO 11 RACES OF *Puccinia graminis Avenae*

Varieties	C.I. No.	R.L. No.	Physiologic race											
			1	2	3	4	5	6	7	8	10	10a	12	13
Avena sativa														
Hajira × Joanette		811	R	R	I	R	R	R	R	R	R	R	R	R
Hajira × Joanette		800	R	R	I	R	R	MR	R	R	R	R	R	R
Hajira × Joanette		824	R	R	I	R	R	MR	R	R	R	R	R	R
Hajira × Joanette		818	R	R	I	MR	R	MR	R	R	R	R	R	R
Victoria × S-524* Sel. 1225			R	R	R	R	R	MS	R	R	R	R	R	R
Victoria × S-524 Sel. 1228			R	R	R	R	R	MS	R	R	R	R	R	R
Victoria × S-524 Sel. 1273			R	R	R	R	R	MS	R	R	R	R	R	R
Victoria × S-524 Sel. 1282			R	R	R	R	R	MS	R	R	R	R	R	R
Hajira & Banner Sel. 524			R	R	R	R	R	S	R	R	R	R	R	R
Joanette Strain	2660	561	R	S	R	R	MR	S	S	S	MS	R	MR	MR
Sevnothree	3251	562	R	S	R	R	MR	S	S	S	MS	R	MR	MR
Hajira	1001	559	R	R	R	S	R	S	R	S	S	S	R	S
Iogold	2329	387	R	R	R	S	R	S	R	S	S	S	R	S
Green Russian, N.D. 22005		1297	R	R	R	S	R	S	R	S	S	S	R	S
Monarch Sel.	1879	363	R	R	R	S	R	S	R	S	S	S	R	S
Richland	787	172	R	R	R	S	R	S	R	S	S	S	R	S
Rusota	2343	371	R	R	R	S	R	S	R	S	S	S	R	S
Vanguard		7	R	R	R	S	R	S	R	S	S	S	R	S
Victoria × S-524 Sel. 909			R	R	R	S	R	S	R	S	S	S	R	S
Victoria × S-524 Sel. 921			R	R	R	S	R	S	R	S	S	S	R	S
Victoria × S-524 Sel. 922			R	R	R	S	R	S	R	S	S	S	R	S
Anthony	2143	1075	MR	MR	S	S	MR	S	S	MR	MR	MR	S	S
Green Russian	2890	1093	MR	MR	S	S	MR	S	S	MR	MR	MR	S	S
Minnesota 439		243	MR	MR	S	S	MR	S	S	MR	MR	MR	S	S
Minrus	2144	1078	MR	MR	S	S	MR	S	S	MR	MR	MR	S	S
Abundance		844	S	S	S	S	S	S	S	S	S	S	S	S
Alaska		165	S	S	S	S	S	S	S	S	S	S	S	
Awnless Rust Proof	1776	773	S	S	S	S	S	S	S	S	S	S	S	S
Banner		1301	S	S	S	S	S	S	S	S	S	S	S	S

* *S-524 = Selection from (Hajira × Banner).*

TABLE III—*Continued*

SEEDLING REACTIONS OF 78 OAT VARIETIES AND HYBRID STRAINS TO 11 RACES OF *Puccinia graminis Avenae*—*Continued*

Varieties	C.I. No.	R.L. No.	Physiologic race											
			1	2	3	4	5	6	7	8	10	10a	12	13
Avena sativa—concluded														
Banner		179	S	S	S	S	S	S	S	S	S	S	S	S
Black Mesdag	1877	784	S	S	S	S	S	S	S	S	S	S	S	S
Cartier		633	S	S	S	S	S	S	S	S	S	S	S	S
Eagle		1131	S	S	S	S	S	S	S	S	S	S	S	S
Erban		1307	S	S	S	S	S	S	S	S	S	S	S	S
Gopher	2027	158	S	S	S	S	S	S	S	S	S	S	S	S
Gold Rain		827	S	S	S	S	S	S	S	S	S	S	S	S
Lanark		1306	S	S	S	S	S	S	S	S	S	S	S	S
Legacy		193	S	S	S	S	S	S	S	S	S	S	S	S
Mabel		1314	S	S	S	S	S	S	S	S	S	S	S	S
Markton	2053	353	S	S	S	S	S	S	S	S	S	S	S	S
Minnesota 295	1295	839	S	S	S	S	S	S	S	S	S	S	S	S
Minota	1285	911	S	S	S	S	S	S	S	S	S	S	S	S
O.A.C. 72		168	S	S	S	S	S	S	S	S	S	S	S	S
O.A.C. 144		171	S	S	S	S	S	S	S	S	S	S	S	S
Trispernia		3	S	S	S	S	S	S	S	S	S	S	S	S
Victory	1145	159	S	S	S	S	S	S	S	S	S	S	S	S
60-Day	1887	902	S	S	S	S	S	S	S	S	S	S	S	S
Avena diffusa														
		1023	S	S	S	S	S	S	S	S	S	S	S	S
		1027	S	S	S	S	S	S	S	S	S	S	S	S
		1028	S	S	S	S	S	S	S	S	S	S	S	S
		1034	S	S	S	S	S	S	S	S	S	S	S	S
Avena sativa orientalis														
Green Mountain	1892	929	MR	MR	S	S	MR	S	S	MR	MR	MR	S	S
White Tartar	551	177	MR	MR	S	S	MR	S	S	MR	MR	MR	S	S
Avena barbata														
C.A.N. 221		1013	S	S	S	S	S	S	S	S	S	S	S	S
C.A.N. 220		1014	S	S	S	S	S	S	S	S	S	S	S	S

TABLE III—*Concluded*

SEEDLING REACTIONS OF 78 OAT VARIETIES AND HYBRID STRAINS TO 11 RACES OF *Puccinia graminis Avenae*—*Concluded*

Varieties	C.I. No.	R.L. No.	Physiologic race											
			1	2	3	4	5	6	7	8	10	10a	12	13
Avena byzantina														
Belar	2760	1310	S	S	S	S	S	S	S	S	S	S	S	S
Bond	2733	1130	S	S	S	S	S	S	S	S	S	S	S	S
Early Ripe		161	S	S	S	S	S	S	S	S	S	S	S	S
Early Ripe		634	S	S	S	S	S	S	S	S	S	S	S	S
Early Ripe 213 M.C.		1303	S	S	S	S	S	S	S	S	S	S	S	S
Kanota	839	805	S	S	S	S	S	S	S	S	S	S	S	S
Red Rust Proof	1815	1311	S	S	S	S	S	S	S	S	S	S	S	S
Ruakura	2025	345	S	S	S	S	S	S	S	S	S	S	S	S
Sunrise	982	1318	S	S	S	S	S	S	S	S	S	S	S	S
Victoria	2401	1006	S	S	S	S	S	S	S	S	S	S	S	S
Sterisel	2891	1227	S	S	S	S	S	S	S	S	S	S	S	S
Avena fatua		18	S	S	S	S	S	S	S	S	S	S	S	S
Avena nuda														
Laurel		167	S	S	S	S	S	S	S	S	S	S	S	S
Liberty	845	760	S	S	S	S	S	S	S	S	S	S	S	S
Avena brevis														
	1783		S	S	S	S	S	S	S	S	S	S	S	S
		1018	S	S	S	S	S	S	S	S	S	S	S	S
		1019	S	S	S	S	S	S	S	S	S	S	S	S
		1020	S	S	S	S	S	S	S	S	S	S	S	S
		1022	S	S	S	S	S	S	S	S	S	S	S	S
Avena strigosa														
	1782	1319	S	S	S	S	S	S	S	S	S	S	S	S
		1041	S	S	S	S	S	S	S	S	S	S	S	S
		1045	S	S	S	S	S	S	S	S	S	S	S	S
Glabrota	2630	1312	S	S	S	S	S	S	S	S	S	S	S	S

(4) Varieties reacting like White Tartar, and including Anthony, Green Mountain, Minrus, Minnesota 439, Green Russian C.I. 2890, and Victory × Black Mesdag. These are moderately resistant to races 1, 2, 5, 8, 10, and 10*a*.

(5) Joanette Strain and Sevnothree which are resistant to races 1, 3, 4, and 10*a* and moderately resistant to races 5, 12, and 13.

(6) Varieties susceptible to all physiologic races. These include the majority of the varieties tested.

Crown Rust

The tests with physiologic races of crown rust are summarized in Table IV Of the varieties tested, the only ones that showed resistance to all nine of the physiologic races employed are Victoria, Trispernia (a recent introduction from Roumania by the Cereal Division, Department of Agriculture, Ottawa), and a number of pure lines derived from the cross Victoria × (Hajira × Banner Sel. 524). Another highly resistant oat is the variety Bond (*A. byzantina*), which showed immunity to all races except the rarely occurring race 45 to which it proved highly susceptible. The resistance of Victoria and Bond has already been reported by Murphy, who found Victoria resistant to 37 physiologic races (14) and Bond immune to six physiologic races including four races not used in the present tests (13). Considerable resistance was also shown by the varieties Ruakura and Glabrota (*A. strigosa*), each of which was found susceptible to only two of the races used in the tests. All other varieties proved susceptible to five or more of the nine races to which they were tested.

A comparison of Tables III and IV will show that the crown-rust resistant varieties Trispernia, Victoria, Bond, Ruakura, and Glabrota are highly susceptible to stem rust. A combination of high resistance to stem rust and to crown rust is, however, possessed by certain of the Victoria × S-524 hybrids. Resistance to these two rusts appears also to have been built up by Stanton *et al.* (23) through crosses of Victoria × Richland and by Murphy *et al.* (15) through crosses of Bond with Iogold and other varieties.

Discussion

The study on the rust reaction of seedlings reported in the present paper shows that there is no lack of available rust-resistant breeding material in either wheat or oats. In *Triticum vulgare* and *Avena sativa* alike, there exist varieties that are highly resistant to all of the physiologic races of their respective stem rusts now common in North America. The tests with leaf rust of wheat were less extensive than those with stem rust inasmuch as only eight physiologic races were used; but as far as can be judged from these tests there exist several varieties of common wheat with a high degree of resistance to this rust.

In the tests with stem rust of wheat, the Australian variety Eureka, a group of strains from Kenya, and the Canadian variety McMurachy show great promise as breeding material owing to their high resistance (immunity

TABLE IV

SEEDLING REACTIONS OF 74 OAT VARIETIES AND HYBRID STRAINS TO 9 RACES OF *Puccinia coronata Avenae*

Variety	C.I. No.	R.L. No.	Physiologic race								
			1	2	3	4	5	6	24	38	45
Avena sativa											
Victoria × S-524* Sel. 1228			R	I	I	R	R	I	I	I	R
Victoria × S-524 Sel. 1273			R	I	I	R	R	I	I	I	R
Victoria × S-524 Sel. 914			R	I	R	R	R	I	I	I	R
Victoria × S-524 Sel. 909			R	R	I	R	R	I	I	I	R
Victoria × S-524 Sel. 907			R	R	R	R	R	I	I	I	R
Victoria × S-524 Sel. 921			R	R	R	R	R	I	I	I	R
Victoria × S-524 Sel. 922			R	R	R	R	R	I	I	I	R
Victoria × S-524 Sel. 1225			R	I	I	R	R	I	R	R	R
Trispernia		3	R	I	R	R	R	R	R	R	R
Joanette	2660	561	S	R	MR	S	S	R	I	I	S
Hajira × Joanette		800	S	R	MR	S	S	R	R	R	S
Hajira × Joanette		818	S	R	MR	S	S	R	R	R	S
Hajira × Joanette		824	S	R	MR	S	S	R	R	R	S
Anthony	2143	1075	S	I	S	I	I	S	S	I	S
Green Russian	2890	1093	S	I	S	I	I	S	S	I	S
Minrus	2144	1078	S	R	S	R	I	S	S	R	S
Mabel		1304	S	R	R	S	S	S	I	R	S
Lanark		1306	S	R	R	S	S	S	I	R	S
Victoria × S-524 Sel. 1282			S	S	S	MS	MS	R	R	R	S
Minota	1285	911	S	S	S	S	S	MS	S	S	S
Abundance		844	S	S	S	S	S	S	S	S	S
Alaska		165	S	S	S	S	S	S	S	S	S
Awnless Rustproof	1776	773	S	S	S	S	S	S	S	S	S
Banner		1301	S	S	S	S	S	S	S	S	S
Black Mesdag	1877	784	S	S	S	S	S	S	S	S	S
Cartier		633	S	S	S	S	S	S	S	S	S
Eagle		1131	S	S	S	S	S	S	S	S	S
Erban		1703	S	S	S	S	S	S	S	S	S
Gold Rain		827	S	S	S	S	S	S	S	S	S
Gopher	2027	158	S	S	S	S	S	S	S	S	S
Hajira	1001	559	S	S	S	S	S	S	S	S	S
Hawkeye	2264	1313	S	S	S	S	S	S	S	S	S
Iogold	2329	387	S	S	S	S	S	S	S	S	S
Legacy		193	S	S	S	S	S	S	S	S	S
Markton	2053	353	S	S	S	S	S	S	S	S	S
Minnesota 295	1295	839	S	S	S	S	S	S	S	S	S
Monarch		560	S	S	S	S	S	S	S	S	S
O.A.C. 72		168	S	S	S	S	S	S	S	S	S
O.A.C. 144		171	S	S	S	S	S	S	S	S	S
Richland	787	172	S	S	S	S	S	S	S	S	S
Vanguard		7	S	S	S	S	S	S	S	S	S
Victory	1145	159	S	S	S	S	S	S	S	S	S
Sixty-Day	1887	902	S	S	S	S	S	S	S	S	S
Avena diffusa											
		1023	S	S	S	S	S	S	S	S	S
		1027	S	S	S	S	S	S	S	S	S
		1028	S	S	S	S	S	S	S	S	S
		1034	S	S	S	S	S	S	S	S	S
Avena sativa Orientalis											
Green Mountain	1892	929	S	I	S	I	I	S	S	I	S
White Tartar	551	177	S	I	S	I	I	S	S	I	S

* *S-524 = Selection from (Hajira × Banner).*

TABLE IV—*Concluded*

SEEDLING REACTIONS OF 74 OAT VARIETIES AND HYBRID STRAINS TO 9 RACES OF *Puccinia coronata Avenae*—*Concluded*

Variety	C.I. No.	R.L. No.	Physiologic race								
			1	2	3	4	5	6	24	38	45
Avena barbata											
C.D. 997			S	S	S	S	S	S	S	S	S
A. barbata C.A.N. 221		1013	S	S	S	S	S	S	S	S	S
A. barbata C.A.N. 220		1014	S	S	S	S	S	S	S	S	S
Avena byzantina											
Victoria	2401	1006	R	I	I	R	R	I	I	I	R
Bond	2733	1130	I	I	I	I	I	I	I	I	S
Ruakura	2025	345	S	I	I	S	R	I	I	I	MR
Red Rustproof	1815	1311	S	I	I	S	S	S	I	I	S
Sterisel	2891	1227	S	I	I	S	S	S	I	I	S
Sunrise	982	1318	S	I	I	S	S	S	I	I	S
Early Ripe 213 M.C.		1303	S	I	R	S	S	S	R	R	S
Belar	2760	1310	S	R	R	S	S	S	R	R	S
Kanota	839	805	S	S	S	S	S	MS	S	S	S
Early Ripe		634	S	S	S	S	S	S	S	S	S
Early Ripe		161	S	S	S	S	S	S	S	S	S
Avena fatua		18	S	S	S	S	S	S	S	S	S
Avena nuda											
Laurel		167	S	S	S	S	S	S	S	S	S
Liberty	845	760	S	S	S	S	S	S	S	S	S
Avena brevis											
	1783		S	S	S	S	S	S	S	S	S
		1018	S	S	S	S	S	S	S	S	S
		1019	S	S	S	S	S	S	S	S	S
		1020	S	S	S	S	S	S	S	S	S
		1022	S	S	S	S	S	S	S	S	S
A. strigosa											
Glabrota	2630	1312	I	I	I	I	I	I	S	S	I
		1041	S	S	S	S	S	S	S	S	S
		1045	S	S	S	S	S	S	S	S	S
	1782	1319	S	S	S	S	S	S	S	S	S

at ordinary temperatures) to all the 20 physiologic races used in the tests. The immunity possessed by non-*vulgare* varieties, such as Iumillo, is of less practical importance to plant breeders on account of the difficulty of crossing them with *vulgare* wheats and the danger of introducing undesirable non-*vulgare* characters into the hybrid progeny. Quite apart from the immunity or near-immunity possessed by the above mentioned varieties, there is available to plant breeders the so-called mature-plant resistance possessed by varieties derived from crosses with Hope and H 44. The resistance to stem

rust of such varieties is much greater than the seedling reactions indicate owing to the tendency on the part of these varieties to become more resistant in the more advanced stages of growth.

As pointed out elsewhere in this paper, all the above-mentioned varieties failed to show their characteristic rust reactions at constant high temperatures. The immunity of McMurachy, Eureka, and the Kenya strains was altered to moderate or even complete susceptibility; the mature-plant resistance of Hope, to moderate resistance or moderate susceptibility; and the immunity of Iumillo was occasionally altered to moderate resistance. In view of these results it seems possible that the diminution of rust resistance by high temperatures is a general phenomenon applicable to many varieties. The breakdown of the immunity or resistance of these varieties at high temperatures is probably not of great significance in respect to their field resistance, except perhaps in regions where temperatures are excessively high for considerable periods.

Unfortunately, the *vulgare* varieties most highly resistant to stem rust are susceptible to leaf rust, but, as there exist in the *vulgare* group varieties with high resistance to leaf rust, there should be no great difficulty in combining resistance to leaf rust and stem rust. Hybrid progeny possessing apparently resistance to these two rusts has, in fact, been obtained recently at the Dominion Rust Research Laboratory from crosses of the stem-rust resistant varieties Kenya R.L. 1373 and McMurachy with derivatives of H 44 that are resistant to leaf rust.

The tests conducted on the reaction of oat varieties to physiologic races of oat stem rust and of crown rust should furnish a valuable guide to the field reaction of the varieties tested owing to the fact that, in oats, the reactions of the seedling and the mature plant resemble each other closely. As these tests comprised all but two of the known races of oat stem rust and most of the prevailing races of crown rust, they may be regarded as quite comprehensive. From the tests with stem rust, it appears that oat varieties show less variability in their reactions to stem rust than do wheat varieties. In fact, as already pointed out, the oat varieties tested may be divided into six groups according to their stem-rust reactions. In two of these groups are found varieties with high stem-rust resistance. Derivatives of the cross Hajira × Joanette are resistant to all the physiologic races used in these tests, and certain strains descended from the cross Victoria × (Hajira × Banner Sel. 524) are resistant to all but one of these races. The latter strains possess the further advantage of being highly resistant to crown rust.

In the tests with crown rust, the varieties Victoria and Trispernia, and the above mentioned hybrid lines descended from the cross Victoria × (Hajira × Banner Sel. 524), showed resistance to the nine races used in the tests, while the variety Bond proved immune to eight of these races.

Of all the oat varieties dealt with in the present paper, the only ones combining a high resistance to crown rust and stem rust are the Victoria × (Hajira × Banner Sel. 524) hybrid lines.

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EFFECT OF PHYTOHORMONE DUST SEED TREATMENT ON GROWTH AND YIELD OF BARLEY UNDER GREENHOUSE CONDITIONS[1]

By J. W. Hopkins[2]

Abstract

Under controlled conditions of air temperature and soil moisture, the growth and yield of barley from seed dusted with 2.5 and 5 p.p.m. of indolylacetic acid in talc was compared with that from control seed dusted with talc only. Neither concentration affected germination. Both accelerated the incidence of tillering by one or two days, but did not increase the final number of shoots produced. With sub-optimal soil moisture both phytohormone concentrations increased the height of the plants by about 3% and the dry weight of straw by about 10%, but did not increase the yield of grain. No demonstrable effect upon the yield of either straw or grain was observed in a parallel series of plants receiving a more plentiful supply of moisture.

Introduction

Although many details still remain to be investigated, the physiological activity of minute concentrations of the so-called phytohormone chemicals in promoting the rooting of plant cuttings of certain species is now definitely established. The circumstances in which the application of phytohormones to seeds prior to planting may be expected to stimulate the subsequent growth of field and garden crops are, however, as yet uncertain. Stier and duBuy (3), for example, report statistically significant acceleration of flowering and increase in early and total yield of tomatoes following treatment of the seed with auxin-talc dust mixtures and subsequent dipping of the roots into solutions of either indolylbutyric or naphthylacetic acid at the time of field transplanting. On the other hand, Templeman (4) noted no significant increase in the dry-matter production of barley or mustard grown with restricted or ample nitrogen supply following the application of phytohormone substances, either by spraying on the foliage or by watering. Soaking mustard seed for 24 hr. in solutions of phytohormone before planting likewise failed to result in any stimulation of subsequent growth.

Greenhouse experiments in these laboratories by Grace (1) suggested some increase in the germination and early growth of wheat from the treatment of the seed with carrier dusts containing small quantities of phytohormones. However, the subsequent results of a fairly extensive series of co-operative field trials indicated that although indolylacetic and naphthylacetic acids (the two substances tested) are potentially capable of physiological activity when applied in this way (2), yet in practice these potentialities are manifested only under conditions that are of rather restricted occurrence. Why this should be so is not yet clear, but it seems reasonable to suppose that the

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operation of environmental factors is at least partly responsible. If, for example, the primary effect of phytohormones is to stimulate root formation, it is conceivable that their application might prove to be most advantageous to a crop growing under moderately sub-optimal moisture conditions; for if the supply is abundant, the intensive exploitation of soil moisture by the root system will not be a factor limiting yield, and in the event of extreme drought, crop failure must be expected irrespective of treatment. In order to explore this possibility in a preliminary way, the further greenhouse experiment now described was undertaken.

Experimental

Elite seed of the variety O.A.C. 21, supplied by the Department of Field Crops, University of Alberta, was used. Two concentrations of indolylacetic acid, namely 2.5 and 5 p.p.m. by weight of the seed, were applied in a talc carrier dust at the rate of ½ oz. per bushel. The weighed quantity of grain to be treated was placed in a wide-mouthed glass vessel, the dust added, and the whole rotated mechanically for 10 min. to effect thorough dispersal. A control batch of seed, dusted with talc only, was prepared in the same way.

The experimental plants were grown in ordinary 5½ in. flower pots, each of which contained 1 kg. of steam-sterilized soil. Two seeds per pot were planted at a depth of 1 in., but subsequent thinning, by random selection, reduced the number of plants carried through to maturity to one per pot. Forty replicate pots were sown to each treatment, including the control. At the outset, all grew under the same conditions, water being added by weight every second or third day so as to bring the moisture content of the soil up to 30%, which was about half the moisture-holding capacity of 59%. As soon as germination was complete, however, the moisture supply of half the replicates of each treatment was restricted, being adjusted to 22.5% instead of 30% throughout the subsequent course of the experiment. The remaining replicates continued at the original 30% level.

The arrangement in the greenhouse was on two benches, one bearing all the pots adjusted to 22.5% soil moisture, and the other all those adjusted to 30%. Within each bench, the grouping was in 20 randomized blocks, each containing one representative of the three treatments. There were thus 20 replications of each combination of phytohormone dosage and soil moisture.

Air temperature was controlled thermostatically. At first a diurnal range of 40 to 55° F. was imposed. This was later increased to 45 to 60°, then to 50 to 70°, and, in the final stages of ripening, the temperature on bright sunny days reached a maximum of 80° or more.

Seeding took place on January 20, and harvesting on 14 and 15 June, 1939.

Results

The first seedlings emerged above ground on February 3, and Table I indicates the numbers observed (from 80 seeds of each treatment planted) on subsequent dates. At first, it seemed that there might be some effect of

TABLE I

Counts of emerged seedlings
(from 80 seeds planted)

Date	Indolylacetic acid dosage		
	0 p.p.m.	2½ p.p.m.	5 p.p.m.
4/2/39	21	26	35
6/2/39	60	47	55
8/2/39	77	77	77
10/2/39	79	79	80
13/2/39	80	80	80

treatment upon germination rate, but the later counts suggest that this was a chance result. Final germination was 100% in all cases.

Differential soil moisture supply was imposed on February 9 as described above, and maintained thereafter. Tillering was first noticed on March 9, proceeding as shown in Table II. The appearance of tillers (axillary shoots) in the groups of plants receiving 30% soil moisture was in general from two to three days in advance of that in the groups receiving only 22.5%. Furthermore, at 30% soil moisture, both concentrations of indolylacetic acid used accelerated the tillering process by about one day. There is some suggestion of a similar tendency in the results at 22.5% soil moisture, but here the effect is not nearly so pronounced. By March 21 practically all the plants, irrespective of treatment, had at least one axillary shoot.

Beginning on February 20, the height of the main tiller of each plant was measured at weekly intervals. The resulting treatment averages are shown in Table III. The first five sets of these averages are each deduced from

TABLE II

Numbers of plants (out of 40) with axillary shoots

Date	Soil moisture, 22.5%				Soil moisture, 30%			
	Indolylacetic acid dosage			Total	Indolylacetic acid dosage			Total
	0 p.p.m.	2½ p.p.m.	5 p.p.m.		0 p.p.m.	2½ p.p.m.	5 p.p.m.	
9/3/39	0	1	0	1	3	7	6	16
10/3/39	1	3	1	5	7	15	14	36
11/3/39	4	5	3	12	10	20	20	50
12/3/39	9	15	15	39	22	30	30	82
13/3/39	15	18	22	55	22	33	33	88
14/3/39	26	32	30	88	35	35	39	109
15/3/39	32	36	36	104	36	38	40	114
16/3/39	34	36	36	106	40	38	40	118
17/3/39	35	37	37	109	40	38	40	118
19/3/39	39	40	38	117	40	38	40	118
20/3/39	39	40	38	117	40	38	40	118
21/3/39	39	40	39	118	40	39	40	119

40 replicate plants, and the remainder from 20, the number of plants having been reduced to one per pot on March 26. A significant difference between the mean height of all plants receiving 30% soil moisture and that of all those receiving 22.5% was soon apparent, and became progressively greater as development proceeded. It was not, however, until April 17 that any difference ascribable to phytohormone treatment manifested itself. At that date, the mean for all plants receiving indolylacetic grown at 22.5% soil moisture became slightly but significantly higher than the corresponding control value. This difference persisted until the cessation of elongation on May 1, when it was of the order of 3%. By this time the plants receiving 30% soil moisture were on the average about 20 cm. taller than those produced under the more restricted moisture supply, but on no occasion was any effect of chemical treatment on plant height detectable within this group.

TABLE III

AVERAGE HEIGHT OF MAIN TILLER (CM.) TO TIP OF TALLEST LEAF OR OF APICAL GLUME

Date	Soil moisture, 22.5%				Soil moisture, 30%			
	Indolylacetic acid dosage			Average	Indolylacetic acid dosage			Average
	0 p.p.m.	2½ p.p.m.	5 p.p.m.		0 p.p.m.	2½ p.p.m.	5 p.p.m.	
20/2/39	11.8	11.8	12.0	11.8	11.9	11.9	12.3	12.0
27/2/39	14.7	14.7	14.1	14.5	14.7	15.3	15.5	15.2
6/3/39	21.1	21.3	21.3	21.2	21.9	22.6	23.3	22.6
13/3/39	24.5	25.2	24.7	24.8	26.8	28.4	28.7	28.0
20/3/39	29.2	29.5	29.6	29.4	33.2	33.9	34.3	33.8
27/3/39	34.4	36.4	36.2	35.7	40.0	41.2	41.8	41.0
3/4/39	38.7	39.4	39.8	39.3	46.2	47.8	47.9	47.3
10/4/39	49.0	50.1	49.8	49.6	60.8	61.9	62.6	61.8
17/4/39	62.2	63.5*	63.8*	63.2	78.4	79.7	79.8	79.3
24/4/39	69.8	72.1*	72.2*	71.4	91.2	91.6	92.8	91.9
1/5/39	70.4	72.8*	72.5*	71.9	93.4	93.7	93.5	93.5
8/5/39	—	—	—	—	93.6	93.8	94.6	94.0

* *Significantly exceeds control.*

Emergence of heads began on April 16, and was completed in the main tillers of both moisture groups by April 25, with no indication of any treatment effect (Table IV). In the side tillers it continued intermittently until May 17. A total of 35 of the secondary shoots of the plants growing at 30% soil moisture produced heads, as compared with only four of those at 22.5%. Here again, however, there was no discernible effect of the indolylacetic acid applications.

Maturity was actually attained about a week earlier under the conditions of restricted moisture supply, but both crops were harvested at the same time, namely June 14 and 15. Air-dry weight of straw, weight of grain and number of kernels were determined for each plant individually, the treatment averages of these quantities being given in Table V. As would be expected, the productivity of the plants receiving the more liberal supply of soil moisture

TABLE IV

NUMBER OF HEADS FULLY EMERGED, I.E., BASAL NODE OF RACHIS ABOVE LIGULE OF TOP LEAF SHEATH

Date	Soil moisture, 22.5%				Soil moisture, 30%			
	Indolylacetic acid dosage			Total	Indolylacetic acid dosage			Total
	0 p.p.m.	2½ p.p.m.	5 p.p.m.		0 p.p.m.	2½ p.p.m.	5 p.p.m.	
16/4/39	1	0	0	1	0	2	1	3
17/4/39	2	1	1	4	1	3	2	6
18/4/39	3	3	2	8	5	8	5	18
19/4/39	7	10	5	22	13	17	19	49
20/4/39	9	14	10	33	16	17	20	53
21/4/39	14	16	16	46	17	18	20	55
22/4/39	18	19	19	56	17	20	20	57
23/4/39	18	20	20	58	18	20	20	58
24/4/39	19	20	20	59	19	20	20	59
25/4/39	20	20	20	60	20	20	20	60
27/4/39	20	20	20	60	22	22	21	65
29/4/39	20	20	20	60	23	23	23	69
1/5/39	20	20	20	60	23	23	24	70
3/5/39	20	20	20	60	24	24	26	74
3/5/39	20	20	20	60	25	25	27	77
7/5/39	20	20	20	60	25	26	28	79
10/5/39	20	20	21	61	30	28	31	89
12/5/39	20	21	22	63	32	29	33	94
17/5/39	21	21	22	64	33	29	33	95

was markedly the greater. Analyses of variance indicate that at 22.5% the weight of straw secured from the seed dusted with either 2.5 or 5 p.p.m. of indolylacetic acid was significantly greater, by about 10%, than that resulting from the control seed dusted with talc only. There was, however, no significant difference in the corresponding weights of grain. In the 30% moisture series, no effect of chemical treatment upon the weight of either grain or straw was demonstrable. The average number of kernels per plant likewise showed no significant treatment difference under either moisture regime.

TABLE V

YIELD OF STRAW AND GRAIN

Item	Soil moisture, 22.5%				Soil moisture, 30%			
	Indolylacetic acid dosage			Average	Indolylacetic acid dosage			Average
	0 p.p..m	2½ p.p.m.	5 p.p.m.		0 p.p.m.	2½ p.p.m.	5 p.p.m.	
Av. wt. of straw per plant, g.	1.04	1.13*	1.15*	1.11	1.83	1.73	1.87	1.81
Av. wt. of grain per plant, g.	1.87	1.94	1.93	1.91	2.96	2.64	2.81	2.80
Av. no. of kernels per plant	45	46	46	46	70	64	68	67

* *Significantly exceeds control.*

It cannot be said that the results of this experiment as a whole are at all striking. They do however provide some further evidence for the supposition that beneficial effects from the phytohormone dust treatment of seeds may be forthcoming only under certain limiting conditions, and that stimulation of growth or yield in the field should not be expected to be of general occurrence.

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AN ABERRANT STRAIN OF PUCCINIA HELIANTHI SCHW.[1]

BY A. M. BROWN[2]

Abstract

The aberrant strain of rust here discussed was first observed in haploid infections arising from germinating teliospores of the *tuberosus* strain of *Puccinia Helianthi*. The teliospores occurred on a single leaf of *Helianthus tuberosus*. Teliospores on several other leaves of the same collection were induced to germinate, but their sporidia produced only normal infections. This strain of rust differed from the parent strain in colour, pathogenicity, spore viability, and host range, and was parctically intersterile with it. It also differed in urediospore size, shape, and echinulation, and in ability to withstand warm temperatures. It is suggested that these differences were probably due to a mutation in which the loss or gain of chromatin carrying more than one gene was involved.

Introduction

Owing to the intensive study to which certain of the plant rusts have been subjected in recent years, opportunity has been given for observing changes and aberrancies that might have otherwise passed unnoticed. For example, in *Puccinia graminis Tritici* Erikss. and Henn., Newton and Johnson (5) and Waterhouse (10) discovered spontaneous changes in spore colour, and Stakman, Levine, and Cotter (9), and Newton and Johnson (6), spontaneous changes in pathogenicity. All these changes were attributed to mutations. In *Puccinia triticina* Erikss., Johnston (4) reported an aberrant race differing from known races in length of incubation period, spore colour, and size of urediospores, and Roberts (8) described a mutation for pathogenicity. Gassner and Straib (3) recorded a mutation for pathogenicity in *Puccinia glumarum Tritici* (Schmidt) Erikss. and Henn., and d'Oliveira (7), one for colour and pathogenicity in *Puccinia anomala* Rostr.

For some years *P. Helianthi* has been studied at this laboratory, where it was shown to be heterothallic (2) and to comprise several well defined strains (1), one of which is specialized to *Helianthus tuberosus* L. and known as the *tuberosus* strain. Early in 1936, monosporidial infections of this strain were under observation, and among them were detected occasionally infections that were whitish in colour but otherwise apparently normal. These aberrant infections produced hyaline paraphyses and pycniospores, and colourless nectar. As a rule they failed to attain the diameter of the normal infections in the same cultures.

This particular strain of *Puccinia Helianthi*, as already reported (1), was collected on an isolated patch of *Helianthus tuberosus* growing near the Red River. The collection was made from the same clump of plants from which collections had been made in previous years. Pathogenically the strain

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seemed to be homozygous, for cultures of it had been selfed yearly during the five preceding years and each year the same pathogenic strain was isolated. The telial material used as a source of inoculum for the present study was collected early in November, 1935. The usual inoculation procedure was followed. A leaf bearing numerous telia was randomly selected, soaked in water, and dried several times in succession, and, when sporidial production became abundant, the leaf was suspended over seedling plants of *Helianthus annuus* L.

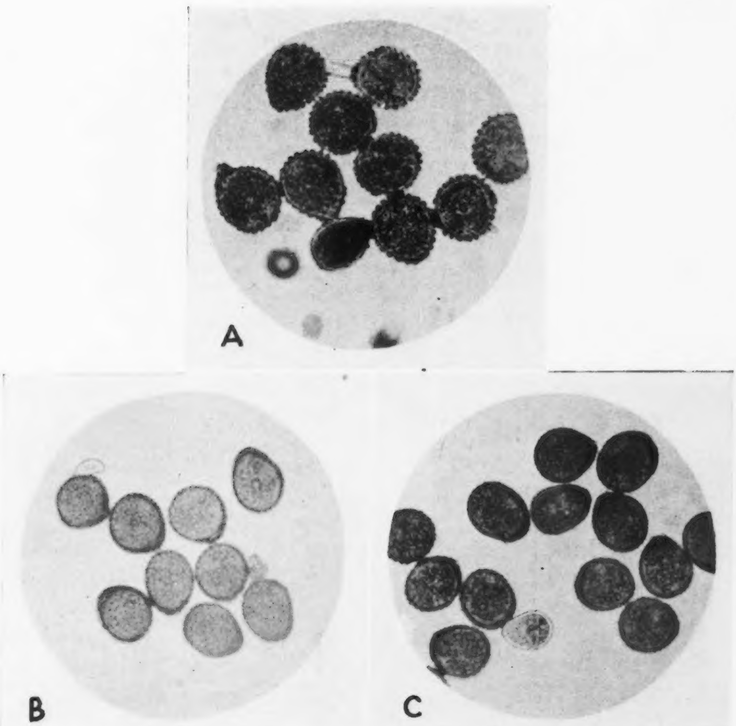
From the telia of the first leaf used for inoculation purposes there arose a number of haploid infections among which were three that were whitish. These three occurred haphazardly among, but well isolated from the other infections. When they were 21 days old, their scantily produced colourless nectar, resembling drops of glycerine, was intermixed, each one of the three infections receiving nectar from the other two. Fortunately the three haploid infections were not all of the same sex, and several days after the nectra transfer they all produced whitish aecia and aeciospores. These aeciospores germinated less vigorously than did those produced concurrently in normal infections similarly selfed. When sown on seedling hosts, they produced uredia and urediospores, both greyish.

As the leaf bearing the telia was not discarded after the first inoculation, it was used at two-week intervals for further inoculations, until teliospore germination failed towards the end of March. In each set of cultures established from the telia on this leaf, occasional white infections appeared. Altogether, 10 additional ones were obtained that were well separated from any other infections, and in these, too, aecia were induced to develop. In mass, the aeciospores, like those just referred to above, were whitish and gave rise to infections that produced greyish-coloured urediospores and teliospores. Although teliospores on several other leaves of the same collection were induced to germinate, their sporidia produced only normal infections.

Comparison of Normal and Aberrant Urediospores

The aberrant urediospores, as can be seen in Plate I, B, are readily distinguishable from those of the normal *tuberosus* strain, Plate I, A, on account of their pale appearance. Moreover, they are smoother and smaller than those of that strain. By projecting on a screen the images of 100 urediospores from each of two different generations of the aberrant and of the *tuberosus* strain at a magnification of 500, the spore sizes given in Table I were secured. For comparative purposes, similar measurements were obtained for urediospores of the *annuus* strain, a strain apparently capable of attacking only *Helianthus annuus*. From these data it is evident that there is a distinct difference between the size of the urediospore of the aberrant and that of the urediospore of the normal strains. In the two generations referred to, the urediospores of the *tuberosus* strain were consistently larger than the urediospores of the aberrant or of the *annuus* strain, those of the two latter strains being much the same in size.

PLATE I



A. Urediospores of the tuberosus strain. They are very rough in outline. ×360. B. Urediospores of the aberrant strain. Owing to their greyish colour, these spores appear somewhat hazy in the photograph. ×360. C. Urediospores of the annuus strain. ×360.

TABLE I

THE MEAN LENGTH AND WIDTH OF UREDIOSPORES AND THE STANDARD ERROR OF MEAN, FOR TWO GENERATIONS OF SPORES

	Mean spore length in μ	Mean spore width in μ
1st urediospore generation		
Tuberosus strain	28.8 $\pm$ 0.013	25.5 $\pm$ 0.011
Annuus strain	24.9 $\pm$ 0.010	21.6 $\pm$ 0.007
Aberrant strain	23.7 $\pm$ 0.011	19.7 $\pm$ 0.011
2nd urediospore generation		
Tuberosus strain	29.6 $\pm$ 0.048	25.6 $\pm$ 0.048
Annuus strain	24.5 $\pm$ 0.014	21.4 $\pm$ 0.007
Aberrant	24.5 $\pm$ 0.010	21.1 $\pm$ 0.013

These differences in spore character are further shown in Plate I, which shows urediospores of the three strains photographed at an identical magnification. The spores of the normal *tuberosus* strain show pronounced echinulation, while those of the other two strains are more finely echinulate.

Pathogenicity of the Three Strains

In a previous investigation (1), the *tuberosus* and *annuus* strains proved to be quite dissimilar in host range. For the purpose of comparing the pathogenicity of the aberrant strain with that of each of the other two strains, the following hosts were inoculated with urediospores of each of the three strains: *Helianthus annuus*, *H. subrhomboideus* Rydb., *H. Maximiliani* Schrad., *H. subtuberosus* Bourg., and *H. tuberosus*. All these hosts were raised from seed, except *H. tuberosus*, which grew from tubers procured from the location at which the telial material of the *tuberosus* strain was collected.

The results of this experiment, shown in Table II, indicate that the three strains differ in their pathogenic capabilities. The aberrant strain, although derived from the same telial material as the normal *tuberosus* strain differed from it in host range and pathogenicity. It attacked *Helianthus tuberosus* only weakly and *H. subtuberosus* and *H. subrhomboideus* not at all, whereas

TABLE II

THE REACTIONS OF FIVE SPECIES OF *Helianthus* TO UREDIOSPORE INOCULATION OF THE *tuberosus*, *annuus*, AND ABERRANT STRAINS

Source of urediospore inoculum	*H. annuus*	*H. subrhomboideus*	*H. maximiliani*	*H. subtuberosus*	*H. tuberosus*
Tuberosus strain	S*	S*	O	S	S
Annuus strain	S	O	O	O	O
Aberrant strain	S	O	O	R	R

S = *susceptible;* R = *resistant, with minute infections;* O = *immune.*
* *Uredia produced on upper leaf-surface only.*

the normal strain attacked all three vigorously. Like the *tuberosus* strain, it infected readily *Helianthus annuus*. the only one of the five hosts attacked by the *annuus* strain. It was less tolerant of warm temperatures than either of the other two strains, for, during the ensuing summer, the aberrant strain became progressively weaker and was finally lost.

Interfertility of the Three Strains

To test the interfertility of the three strains, urediospores of the aberrant strain were sown near to the periphery of 100 monosporidial infections of the *tuberosus* and of 30 similar infections of the *annuus* strains. As a control, aberrant urediospores were sown near the periphery of six aberrant infections. The results of this experiment are shown in Table III. Briefly they show that, 12 days after the inoculation, all the uredial infections had coalesced with the haploid infections, and, at the end of 21 days, three infections of the *tuberosus*, four of the *annuus*, and the six aberrant ones produced aecia.

TABLE III

THE RESULTS OF PAIRING HAPLOID INFECTIONS OF THE *tuberosus*, *annuus*, AND ABERRANT STRAINS, WITH UREDINAL INFECTIONS OF THE ABERRANT STRAINS

Haploid infections	Uredinal infections	No. of haploid infections	No. of infections with aecia
Tuberosus strain	Aberrant strain	100	3*
Annuus strain	Aberrant strain	30	4
Aberrant strain	Aberrant strain	6	6

* *Aeciospores were non-viable.*

The aecia and aeciospores produced by the diploidised infections of the *tuberosus* and *annuus* strains were normal in colour, while those of the aberrant infections were whitish and in every respect similar to the aecia and aeciospores induced earlier in aberrant infections by selfing. In the diploidised infections of the *tuberosus* and *annuus* strains, aecia were sparsely produced and the aeciospores of the former strain failed to germinate. Those of the *annuus* strain, however, showed a trace of germination, although, when sown on *Helianthus annuus* seedlings, they failed to cause infection. On the other hand, aeciospores from the diploidised aberrant infections germinated moderately well and, when sown on *H. annuus* seedlings, produced greyish uredia and urediospores. These urediospores were identical in infection capabilities with those first obtained of the aberrant strain.

Discussion

How this strain of rust originated must remain at least partly a matter of conjecture. During the five years preceding and the three years following the isolation of this aberrant strain, cultures were established from telial

material collected from the same clump of plants as that from which the present telial material was obtained. Although numerous infections were procured in each of those years, no aberrant ones were observed among them. The fact that the sporidia from which the aberrant haploid infections arose were produced only by teliospores from one particular leaf suggests that the mycelium of some telial sorus on that leaf carried a chromosomal irregularity that was responsible for the aberrancies. As already shown, this strain differed from the normal strain in colour, pathogenicity, spore viability, and host range, and was practically intersterile with that strain. It differed also in urediospore size, shape, and echinulation, and in ability to withstand warm temperatures. These differences were probably due to mutation, but, in view of the number of characters involved, it seems unlikely that a single gene, or "point", mutation alone was responsible for them. Rather would it appear that the change involved the loss or gain of chromatin carrying more than one gene.

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REPRODUCTION IN SOME POA SPECIES[1]

By V. Engelbert[2]

Abstract

The writer has demonstrated through breeding experiments repeated over three years, that *Poa arctica* R. Br., *Poa alpigena* Fr. Lindm., *Poa alpina* L. from Greenland as well as *Poa alpina* L. from Georgian Bay, Ontario, and a race of *Poa pratensis* L. from Gaspé, Quebec, are all apomictic (parthenogenic) and pseudogamous. In pseudogamy the pollen-tube enters the stigma and activates the apomictic embryo sac to development, but it does not as a rule enter the ovarian tissue to achieve fertilization of the ovule. Pollen from any one species germinated readily and with a high percentage on the stigmas of any one of the others. Pollen sterility did not exceed 2%.

Introduction

A number of Scandinavian workers have investigated some phases of reproduction in this group of grasses. On the basis of cytological and breeding experiments Müntzing (5) suggested in 1932 that certain races of *Poa alpina* L. and *Poa pratensis* L. were apomictic in their method of reproduction. This was the first demonstration of apomixis in the Gramineae. Aakerberg (1) confirmed this report after breeding experiments with different races of the same species. He also found pseudogamy as a rule, but out of several thousand attempted crosses he (2) succeeded in obtaining a few hybrids of *P. pratensis* × *P. alpina* and between different *pratensis* plants. He has since (3) published further observations on apomictic and sexual seed formation in *Poa pratensis*. Kiellander (4) found apomixis also in *Poa serotina* Ehr.

Experimental

Material:

The species used were:

Poa arctica R. Br. from west Greenland.

Poa alpina L. from west Greenland.

Poa alpigena Fr. Lindm. from west Greenland.

Poa alpina L. from Georgian Bay, Ontario.

Poa pratensis L., a biotype from Gaspé Peninsula, Quebec.

The species from Greenland were grown from seed obtained through the kindness of Mr. M. P. Porsild, Director of the Danish Arctic Station on Disko Island, Greenland. The Canadian material was collected by the writer in 1935 as both seed and as vegetative clones.

Even with greenhouse facilities and a longer day produced by electric light, it takes two years to rear a plant of these species to the flowering stage suitable for experiment.

[1] *Manuscript received June 14, 1940.*
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Breeding Experiments

I. Method

The flowers of the Poas are so small as to require the development of a special technique for emasculation and pollination. To provide sufficient magnification a 30× Leitz binocular microscope was used. The panicle was stuck through the ring of a retort stand while its flowers were being emasculated. While performing this operation the hands rested on the ring so that the necessary steadiness of movement and reasonable efficiency and speed were ensured. The floret was held lightly between the forefinger and thumb of the left hand. A pair of surgeon's "nerve forceps" with curved points were used both for opening the flower by displacing the lemma or palea and removal of the anthers. As soon as the stigmas showed their feathery branches outside the glumes, pollinating was begun. To obtain the pollen a clean glass slide was tapped from below against the ripe protruding anthers. The pollen would then cover the slide as a fine dust and its quality could be observed quickly under a compound microscope. If the quality were satisfactory, the slide was passed gently over the stigma branches of the mother plant. This method ensured that an abundance of pollen was applied without injury to it or the stigmas.

It was very important that the pollen be taken as soon as the anthers showed outside the glumes owing to its extreme sensitivity to such external factors as temperature and the relative humidity of the air. The following observations apply to all the species used and to a location in Ontario at approximately 43½° N. Lat.

As the atmosphere becomes drier and warmer through May and June, the life of the pollen grain becomes progressively shorter. About May 20, anthesis usually takes place between 8 and 10 a.m. At this time sound, undeteriorated pollen can be obtained until noon and on a cool cloudy day over the first part of the afternoon. As the weather gets warmer and drier anthesis takes place much earlier and virtually all the pollen has shrivelled by 6 a.m. on a bright warm morning. On a dull day, anthesis will be delayed until afternoon even in June. Every sample of pollen used for pollination was therefore examined under the microscope to ensure that only sound pollen was applied to the stigmas. This rapid deterioration of the pollen of *Poa* seems never to have been mentioned by other workers. Shrivelled pollen gathers in lumps on the slide when shaken out of the anther but the sound pollen forms a fine dust-like layer.

Aakerberg (1, 2) from his observations classes the pollen as (i) well developed, morphologically good, (ii) not quite full of plasma, or (iii) empty pollen. The writer suggests that (ii) is partly deteriorated pollen and that probably most of the pollen mentioned under (iii) can be classed as completely deteriorated pollen. Very little pollen that was truly sterile was found in the species here studied, its frequency being at the most 1 to 2%. The sterile pollen appears yellowish, whereas the deteriorate pollen is whitish, and thus they can easily be distinguished from each other.

II. Results

A. Breeding Data

The series of experiments here reported were performed in 1936 and repeated in 1937 and again in 1938 with uniformly consistent outcome. The mode of reproduction and the possibilities of natural and artificial hybridization were tested with five different treatments.

(a) Emasculation without subsequent pollination; 1282 flowers were so treated and no seed was produced in any instance.

(b) Emasculation followed by artificial self-pollination; 1049 flowers were treated and from 12 to 30% of them produced seed. No female sterile plant was found.

(c) Emasculation and interspecific cross-pollination; 1549 flowers were treated and from 1.4 to 59% of the flowers set seed. No sterility was found here either. All the progeny resembled closely the mother plant.

(d) Control plants left to natural development but covered with bags produced from 3 to 55 seeds per 100 flowers.

(e) Control plants not covered with bags and left to strictly natural development produced from 13 to 77 seeds per 100 flowers.

The great variation in seed production in isolated plants is due partly to the bagging and partly to climatic conditions. The latter influence is seen in the seed production of control plants not bagged. There is no evidence that any one of these species or any single plant is an especially good or poor seed-producer.

From these results it is evident that pollination is necessary for seed production but that the progeny all resemble the mother parent. The pollen then must act as an activator on the ovule, but actual fertilization does not take place; this is pseudogamy, a type of apomixis.

B. Pollen Germination Studies

The germination of pollen was studied and followed microscopically by mounting whole stigmas in lactic phenol and methyl blue at from 2 to 48 hr. after pollination, with two hour intervals the first day.

The pollen germination was high in all cases whether it belonged to the same or a different species from that of the mother plant. The pollen tubes remained short, having an average length of 2 to 4 pollen grain diameters. Only one exception was found, in self-pollinated stigmas of one plant of *Poa alpina*, where the pollen tubes reached the ovarian tissue. The initial growth of the pollen tubes is quite rapid. Stigmas pollinated about 5 a.m. showed many pollen tubes ranging from one to two pollen grain diameters about 9 a.m. to a maximum of five to eight at 12.00 a.m.

There are, no doubt, differences in the speed of pollen tube growth and in the ultimate length attained depending on the condition of the stigma and of the pollen at the time of application as well as the climatic factors at the

time. Thirty-six hours after pollination the ovaries had increased considerably in size in all specimens examined. These results support the conclusions drawn from the breeding experiments and show that the pollen tube only acts as an activator and not in a genetic capacity.

Conclusions

The species investigated show both from breeding experiments and pollen germination studies that they are apomictic and pseudogamous.

Before the taxonomy of the Poas can be fully outlined and the speciation process properly analysed, it is necessary to know the method of reproduction of the different species and their various geographic races.

The *Poa* species so far investigated are characteristically highly polymorphic. Being preponderantly pseudogamous, these species and their sexual relatives must naturally be given different ratings. From the standpoint of forage crop plant breeding it is important that apomixis can be demonstrated as a mode of reproduction in economically useful species such as *Poa pratensis* L.

The progeny of apomictic or pseudogamous types really are "clones" and the initial selection can also be the final one. One must expect to find both apomictic and sexual races within the one species as well as rare cases of sexual seed-production in the apomictic ones.

An investigation of the development of the male and female gametophyte in the species used here is in progress.

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A ROOT-ROT OF DOUGLAS FIR CAUSED BY *PORIA WEIRII*[1]

BY IRENE MOUNCE[2], J. E. BIER[3], AND MILDRED K. NOBLES[4]

Abstract

A laminated root-rot of Douglas fir [*Pseudotsuga taxifolia* (Lamb.) Britt.] occurs in young stands on Vancouver Island, B.C. The decay, the sporophore associated with it, and the cultural characters of the fungus are described. A comparison with *Poria Weirii* Murr., previously reported only on *Thuja plicata* (D. Don.), shows a close resemblance in all respects between the two fungi.

During the last few years foresters at Cowichan Lake Forest Experiment Station have observed the dying in groups of young Douglas fir trees. The frequent occurrence of such affected areas showed that the trouble was of considerable importance in young second growth stands. Their general appearance suggested at first that *Armillaria* root-rot might be responsible. Recent investigations, however, indicate that, while that disease is present, most of the damage is due to a species of brown *Poria*. Although differing somewhat from *Poria Weirii* Murr. as it is found on western red cedar (*Thuja plicata* D. Don.), the fungus would seem to be that species or a form of it occurring on Douglas fir.

The Disease

Our first record of this disease dates back to November 30, 1929, when Mr. C. G. Riley who was then with the British Columbia Forest Branch, Victoria, sent in for identification two specimens of decay in Douglas fir and the cultures made from them. Both were from the Cowichan Lake Forest Experiment Station. One wood specimen (No. 1277) was taken from the base of a living Douglas fir growing in a pure 18-year-old stand. The discoloration of the heartwood ran up the stem to a height of 3 ft. No fruit-bodies were found. The other specimen (No. 1278) showed mycelial fans beneath the bark. "The fungus appears to be responsible for some serious gaps in an otherwise thrifty stand of Douglas fir twenty years old. Its habit resembles *Armillaria mellea* but the fruit-bodies, if of that species, are atypical." The culture of the first organism is identical with isolates made during the present study, the second is, as Mr. Riley surmised, *A. mellea*.

Geographical Distribution

Observations made so far indicate that this disease occurs generally throughout the southeastern portion of Vancouver Island (Fig. 1). Collections have been made from Saanichton, Duncan, Cowichan Lake, Nanaimo, Parksville,

[1] *Manuscript received June 27, 1940.*
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FIG. 1. *Localities (○) on Vancouver Island, B.C. where root-rot of Pseudotsuga is known to occur.*

Union Bay, Cumberland, and Oyster River. It is not known to be present on the mainland but to date the survey has been limited to the examination of a number of young stands of Douglas fir in the Fraser Valley between Vancouver and Mission. More extensive surveys are to be made during the summer of 1940.

Hosts and Occurrence

Critical field observations on the disease were made in stands located at the Cowichan Lake Forest Experiment Station. Infection was common in 20-, 30-, and 40-year-old Douglas fir and in addition the pathogen has been isolated from rot in 100- and 200-year-old Douglas fir (Plate II, Fig. 2) as well as from western hemlock [*Tsuga heterophylla* (Raf.) Sarg.]. The importance of the disease in older stands of fir and on hemlock is not known at this time.

To determine the incidence of the disease a survey was made of the 35- to 40-year-old Douglas fir occurring in the North Arm area (west of road) of the Station, a location that may be considered as representative of the region. Fig. 2 illustrates the frequency of the infection centres, each of which has a number of diseased and recently killed trees. Although the disease mainly occurred in patches it was not uncommon to find isolated trees that were infected.

Five one-tenth-acre sample plots were established in areas designated as infection centres in Fig. 2 to obtain further information on the number and crown class of the trees killed. A summary of this study is given in Table I.

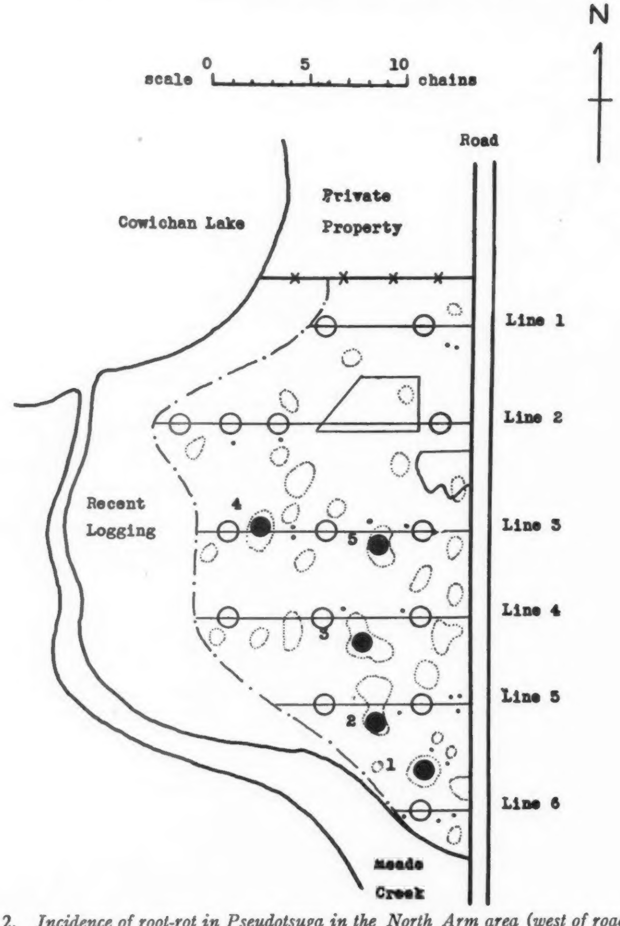


FIG. 2. *Incidence of root-rot in Pseudotsuga in the North Arm area (west of road) of the Cowichan Lake Forest Experiment Station, B.C.*
(○) *Centres of infection.*
(·) *Isolated trees killed during 1939.*
(●) *Location of disease plots.*

It is evident that from 32 to 57% of the trees on the plots have been killed by root-rot. Further, from 19 to 40% of the dominants and co-dominants were affected; this demonstrated that the disease is not confined to the less vigorous trees of the poorer crown classes. It is well to remember that the above figures apply to the infection centres shown in Fig. 2, and not to the stand as a whole.

Figures for Permanent Plot 200 of the British Columbia Forest Service are also included in Table I. All living Douglas firs were tagged in 1935, and,

TABLE I

INCIDENCE OF ROOT-ROT IN DOUGLAS FIR IN THE NORTH ARM AREA (WEST OF ROAD) OF THE COWICHAN LAKE FOREST EXPERIMENT STATION, VANCOUVER ISLAND, B.C.

Plot No.	Number of trees on plot	Number killed by root-rot	Per cent killed by root-rot	Number of dominants and co-dominants on plot	Number of dominants and co-dominants killed by root-rot	Per cent of dominants and co-dominants killed by root-rot
1	34	17	50	22	8	36
2	58	25	43	21	5	24
3	48	25	52	21	4	19
4	19	11	57	5	2	40
5	34	11	32	14	5	36
200	41	10	24	29	8	28

consequently, dead trees which still bear tags have been killed during the last four years. The table shows that during this interval 10 of the 41 tagged trees, i.e., 24% have been killed as the result of root-rot. Eight of the ten trees killed were classified as dominants and co-dominants in 1935.

In most instances trees are killed in groups; this results in stand openings that appear to increase in size gradually. This is illustrated in Fig. 3, which represents diagrammatically one of the permanent sample plots established to obtain further information on the spread of the disease. Wind and snow damage is common and it is possible that the stand openings resulting from root-rot are indirectly responsible for this injury (Plate II, Fig. 1).

Appearance

The first indication of the presence of the disease is a retardation of growth. Infection in the roots interferes with food supply and reduces the current season's growth (Plate I). This is usually accompanied by a "distress" crop of cones, which are smaller than normal. An infected tree may show these signs, accompanied by a gradual thinning of the foliage, for a year or two before there is a browning of all the needles, signifying that the tree is dead. Because of the decayed roots these trees are subject to wind and snow damage and they are commonly found uprooted with the large roots broken off a short distance from the crown (Plate II, Fig. 1). Baxter (1, p. 331) has described a similar condition in stands of *Thuja plicata* attacked by *Poria Weirii.*

Decay

Incipient decay.—A brownish stain characteristic of the incipient stage of decay is usually present on the transverse face of the stump of a recently killed tree (Plate III, Figs. 1–4). The affected area is crescent-shaped to irregular in outline and principally confined to the heartwood, though with frequent patches extending into the sapwood. The discoloration has been

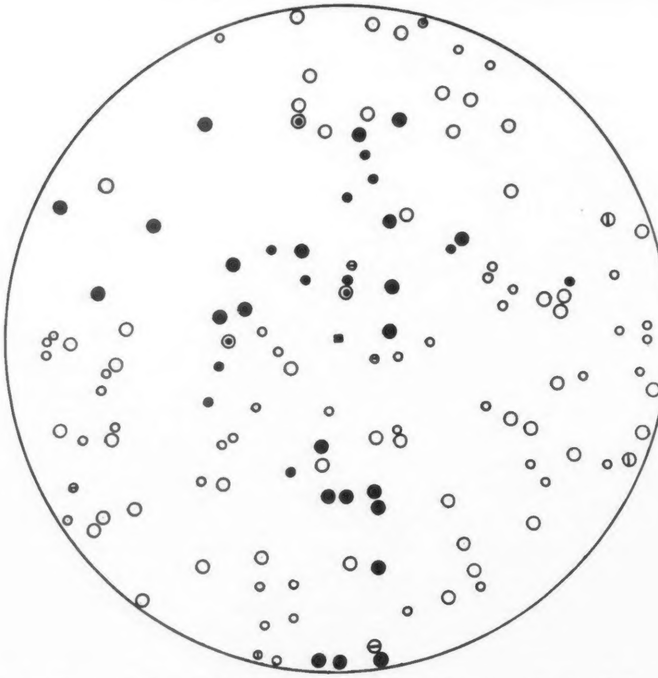


FIG. 3. *Permanent Sample Plot 2, Cowichan Lake Forest Experiment Station, B.C. 1939. Area 0.25 acres.*

(○) *Dominants and Co-dominants.*
(∘) *Intermediate and Suppressed.*
(○) *Pseudotsuga taxifolia.*
(⊖) *Tsuga heterophylla.*
(⦶) *Abies grandis.*
(⊙) *Thuja plicata.*
(●) *Dead, owing to root-rot.*

found for a distance of from 4 to 6 ft. in advance of the later stage. Occasionally there is no rot apparent in the stem above ground and it is found only by exposing the roots.

Advanced decay.—On the transverse face of a stump the advanced decay appears at first as small separated areas. If such a stump is split it is possible to trace each of these areas of rot back to individual decayed roots. Later the entire central core of the stump is rotted, and in a few instances this core of advanced decay has been found to extend for some distance up the trunk of living trees (Plate III, Figs. 5, 6).

In the later stages the wood is soft and flaky, yellowish to brownish, and "honeycombed with small pockets which at first may be filled with whitish fibres but later the pockets are empty." The annual rings separate readily to form a typical ring-scale or laminated rot (Plate III, fig. 5). Tufts of mycelium,

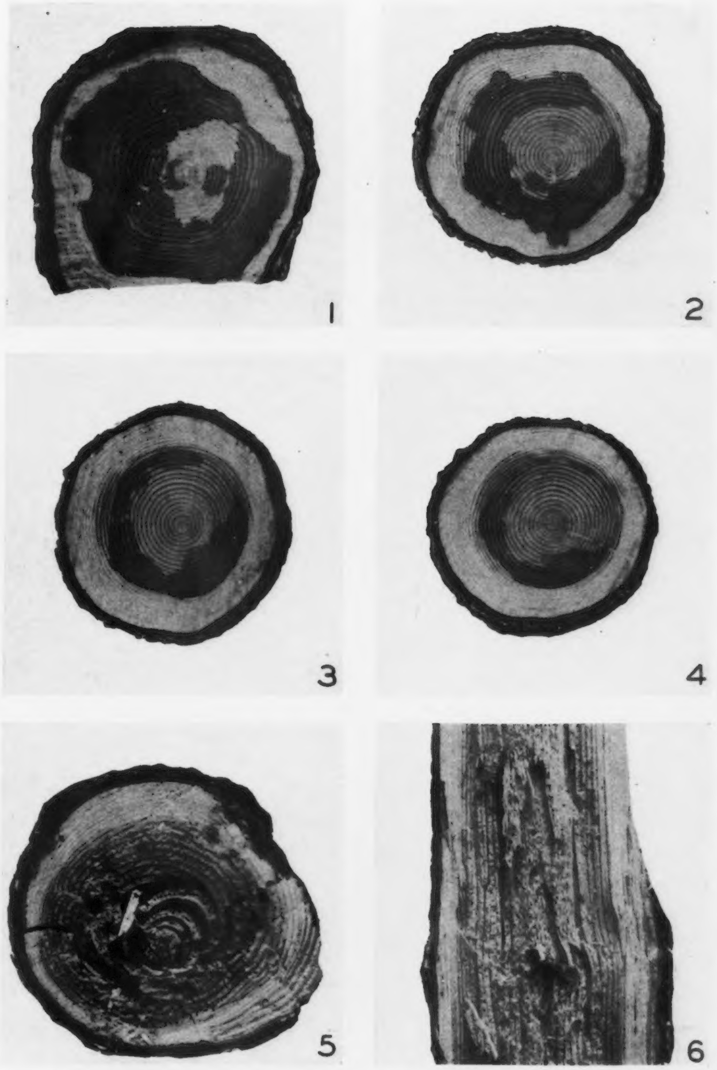
PLATE I

Poria Weirii root-rot in a 20-year-old stand of Pseudotsuga taxifolia at Cowichan Lake Forest Experiment Station, B.C. On the left a diseased tree with thin foliage, in the centre an infected tree with short current growth and "distress" crop of cones, on the right healthy trees.



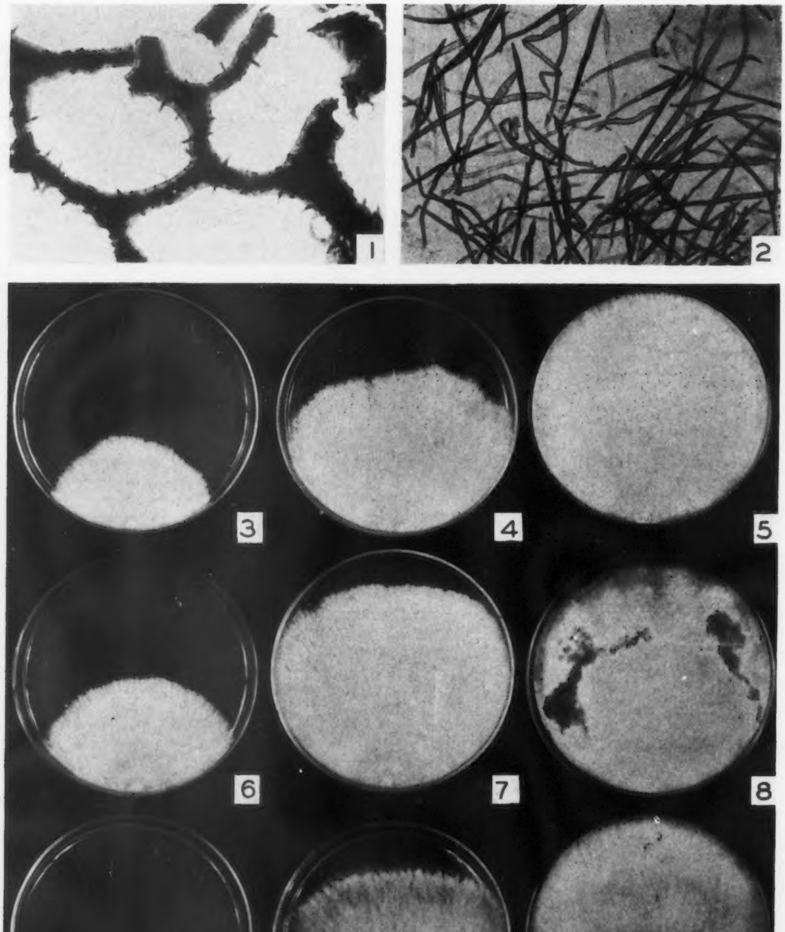

FIG. 1. *Three infected trees uprooted by wind showing the roots broken off at a short distance from the crown.* FIG. 2. *Saprot produced by Poria Weirii in 200-year-old Pseudotsuga at Cowichan Lake Forest Experiment Station, B.C.* FIG. 3. *Young fruit-bodies of Poria Weirii on a stump of Pseudotsuga.* FIG. 4. *Older fruit-bodies on the under side of a stump of Pseudotsuga.*

PLATE III



FIGS. 1 – 4. *Typical appearance of the decay in a 35-year-old stand of Pseudotsuga at Cowichan Lake Forest Experiment Station, B.C.* FIG. 1. *At ground level.* FIG. 2. *Eighteen inches above the ground.* FIG. 3. *Three feet above the ground.* FIG. 4. *Four and one-half feet above the ground.* FIGS. 5, 6. *Decay at breast height in the trunk of a living Pseudotsuga showing the pitted and laminate character of the advanced rot.*

PLATE IV



FIGS. 1 – 8. *Poria Weirii from Pseudotsuga.* FIG. 1. *Cross section of pores of fruit-body, showing setae.* $\times 50$ *approx.* FIG. 2. *Setal hyphae from aerial mycelium of culture.* $\times 120$ *approx.* FIGS. 3 – 5. *Culture from fruit-body tissue, photographed after one, two, and four weeks respectively.* FIGS. 6 – 8. *Culture from rot, photographed after one, two, and four weeks respectively.* FIGS. 9 – 11. *Poria Weirii from Thuja plicata. Culture from rot below fruit-body, photographed after one, two, and four weeks respectively.*

which may coalesce to form sheets, avellaneous and wood brown to army and Natal brown in colour (6) are present in the advanced decay. This mycelium is also found on the outer surface of the bark of diseased roots and on the soil immediately surrounding them. Brown setal hyphae are abundant and readily visible when the mycelium is examined with a hand lens.

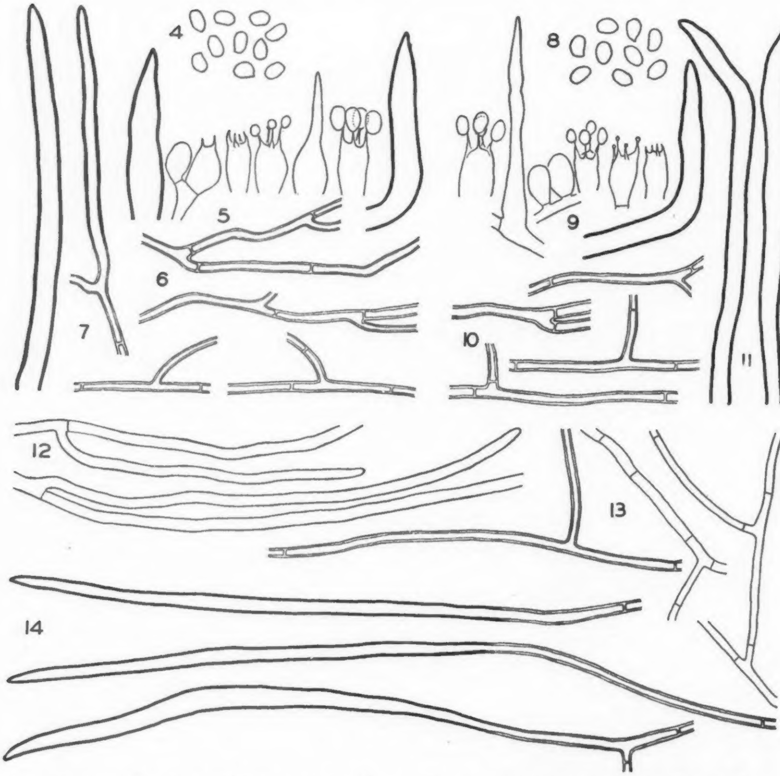
With the exception of the paler avellaneous colour sometimes found in the mycelial mats this rot in Douglas fir does not differ from that caused by *Poria Weirii* in western red cedar. In both, the decay occurs in living trees, is confined largely to the roots and butt, and consequently is indirectly responsible for losses caused by windfall, the affected wood is pitted, the annual rings separate readily, and tufts of mycelium containing setal hyphae are present between the layers. Finally, the sporophores associated with the rots appear to be identical.

The Fungus

Sporophores

In late summer and early autumn, fruit-bodies develop abundantly on the underside of logs, uprooted stumps, and occasionally on the trunks of dead standing trees of *Pseudotsuga* (Plate II, Figs. 3, 4). This fungus, like *Poria Weirii* on *Thuja* (1, p. 331), continues to grow after the tree has been killed, and the sporophores are not found as a rule until the wood is in an advanced stage of decay, i.e., on trees that have been dead for some time.

Sporophores are perennial, light in weight and soft and fragile; effused for a metre or more, separating rather readily from the substratum. In young developing fruit-bodies there is sometimes a broad, sterile margin (Plate II, Fig. 3) cinnamon-buff to pinkish buff and cinnamon later becoming Sudan brown (6); the context is 1 mm. thick, ochraceous, sayal brown to cinnamon-brown; the pore layer 4 mm. thick, the pores somewhat irregular in shape, thin-walled, 4–5 per mm., tawny-olive to Saccardo's umber and Brussels brown, occasionally with the purplish tones of army brown and Natal brown. In older specimens the pore layer is 6–10 mm. thick, deeply cracked, pores 5–6 per mm., the walls thin and entire, uniformly snuff brown, Verona brown or warm sepia (Plate II, Fig. 4). The spores are smooth, hyaline, broadly ellipsoid, becoming oblong-ellipsoid, apiculate at maturity, $4–4.9 \times 2.8–3.2\ \mu$ (Fig. 8); setae abundant (Fig. 11; Plate IV, Fig. 1), pointed, occasionally encrusted, 4–10 μ diameter projecting up to 30 μ, actually the projecting ends of embedded setal hyphae, which are numerous in subiculum and trama (Fig. 11); cystidia (?) hyaline, with bulbous bases and attenuated tips, similar to those in *Poria punctata*, as described by Overholts (5). They appear to be aberrant basidia (Fig. 9). Hyphae of the subiculum are 3.0–4.5 μ diameter, brown, with walls thin or slightly thickened and simple septa, sparingly branched, with, as a rule, "the branches originating at a point median between two adjacent cross-walls," as noted by Overholts (5) in *Poria Weirii* on *Thuja*, but occasionally with branches originating below septa. Hyphae of the trama similar, except that the branches usually originate below septa and rarely midway between septa (Fig. 10).



FIGS. 4 – 7. *Poria Weirii on Thuja plicata.* FIG. 4. *Basidiospores.* ×*800.* FIG. 5. *Setae, cystidium, basidia and basidiospores.* ×*800.* FIG. 6. *Hyphae from context and trama.* ×*450.* FIG. 7. *Setal hyphae.* ×*450.* FIGS. 8 – 14. *Poria Weirii on Pseudotsuga taxifolia.* FIG. 8. *Basidiospores.* ×*800.* FIG. 9. *Seta, cystidium, basidia, basidiospores.* ×*800.* FIG. 10. *Hyphae from context and trama.* ×*450.* FIG. 11. *Setal hyphae.* ×*450.* FIG. 12. *Hyaline hyphae from advancing zone of culture.* ×*450.* FIG. 13. *Coloured hyphae from aerial mycelium of culture.* ×*450.* FIG. 14. *Setal hyphae from aerial mycelium of culture.* ×*450.*

Murrill (4) in his original description of the species gave the spores of *P. Weirii* as "ellipsoid, smooth, hyaline, 5 × 3 μ"; Overholts (5) described them as "globose to subglobose, smooth, hyaline, 4–6 μ diameter". The young sporophores on Douglas fir (Plate II, Fig. 3) are in excellent condition with an abundance of basidia and spores. The spores attached to basidia are globose to subglobose at first but become broadly ellipsoid and finally oblong-ellipsoid with a small apiculus, 4–4.9 × 2.8–3.2 μ (Fig. 8). Although we have specimens of *P. Weirii* on *Thuja* from Bovill and Harvard, Idaho; Marysville, Wash.; Rosebery, Lumby, Robert's Creek, and West Vancouver, B.C., spores were found only in the Rosebery collection. They agreed in size and shape with those from *Pseudotsuga* collections, i.e., young spores

were globose, later becoming oblong-ellipsoid and measuring 3.9–4.9 × 2.7–3.6 μ (Fig. 4).

The sporophores from *Pseudotsuga* do not differ in any fundamental character from *Poria Weirii* on *Thuja* as described by Murrill (4) and later by Overholts (5). The latter fungus may persist for five or six seasons and become 2 cm. thick, whereas so far no specimens of the former have been found to persist for more than two or at most three seasons—perhaps because they are destroyed by insects. Similarly fruit-bodies from the two hosts are identical in their microscopic characters, including size and shape of basidia, basidiospores, cystidia (?), and hyphae (Figs. 4–7 and 8–11). From our measurements the average diameter of the setae in specimens from *Thuja* seems slightly greater than that in specimens from *Pseudotsuga*, the range being 6–13.5 μ (Overholts 6–12 μ) as compared to 4–10 μ. In cultures however the reverse seems to be the case: isolates from *Pseudotsuga* gave setae 4.5–6 (–7) μ while those from *Thuja* were 3–5 μ in diameter. Hence variations in this character are probably not significant.

In any case, the sporophore with its colour, texture, light weight, cracking in older specimens, abundant setae and setal hyphae, and the hyaline, ellipsoid to oblong-ellipsoid spores, the peculiar mode of branching of the hyphae of the subiculum, together with the production of a pitted laminated root- and butt-rot would seem to preclude this fungus on *Pseudotsuga* from being anything but *P. Weirii* or a variety of it.*

It is interesting to note that Korstian and Brush (3) report that in Southern white cedar [*Chamaecyparis thyoides* (L.) B.S.P.] "an unidentified, laminated spongy butt rot is sometimes found, but it has not been possible to connect it with the sporophores of any fungus. In appearance the rot resembles that caused by *Poria Weirii* on western red cedar and may eventually be found to be the same." This suggestion, coupled with our records of its occurrence on *Pseudotsuga* and *Tsuga*, shows that the host range of *Poria Weirii* is wider than previous reports would indicate.

Cultures

Thirty-six isolations of the causal fungus were made from the sources listed in Table II. All the isolates are similar and readily recognizable.

To determine the cultural characters of the fungus and compare them with those of *Poria Weirii* from *Thuja*, 10 isolates of the former and two of the latter were examined according to the procedure used in this laboratory. The cultures are grown on 2% Difco malt agar in 9-cm. Petri dishes in the dark at room temperature, and examined at weekly intervals for six weeks. Observations are made on (i) rate of growth as measured by radius of colony from the inoculum which is placed at the edge of the Petri dish, (ii) colour based on Ridgway's standards, (iii) character of margin, (iv) contour and texture of mat, (v) colour changes in the agar ("Reverse"), and (vi) odour.

**It was not possible to compare the sporophores from Douglas fir with the type material of Poria Weirii since the latter is not available for study just now.*

TABLE II

ISOLATIONS OF THE PATHOGEN

No. of isolations	Host	Source
2	*Pseudotsuga taxifolia*	Stained wood in roots; foliage thin but still green
26	*Pseudotsuga taxifolia*	Rot in roots or base of young living or recently killed trees
1	*Pseudotsuga taxifolia*	Pitted laminated rot in 100-year-old tree
2	*Pseudotsuga taxifolia*	Pitted laminated rot in 200-year-old tree
1	*Pseudotsuga taxifolia*	Rot in root of young living tree with associated purplish-brown mycelial felts
1	*Pseudotsuga taxifolia*	Rot in root of young tree recently killed, with associated purplish-brown mycelium
1	*Pseudotsuga taxifolia*	Context of sporophore on stump of tree fallen two to three years previously
1	*Tsuga heterophylla*	Rot in crown
1	*Tsuga heterophylla*	Rot in stump of freshly cut tree

In addition, the fungus is tested on media containing gallic and tannic acid, following the method described by Davidson, Campbell, and Blaisdell (2). Microscopic examinations are made at suitable intervals, records being kept of the characteristics of the hyphae, occurrence of secondary spores, special structures, etc. Descriptions of the cultures of the *Pseudotsuga* root-rot organism and of *Poria Weirii* follow.

Poria Weirii from Pseudotsuga taxifolia

A. *Macroscopic Characters*

1-week-old cultures.—(Plate IV, Figs. 3, 6) 2.7–3.6 cm. diameter; white; margin sharply defined, of coarse fibres; mat slightly raised, cottony to floccose-cottony, loosely arranged, sometimes with minute tufts scattered over the surface, in some isolates becoming slightly flattened around inoculum; reverse unchanged, odour none. *2-weeks-old cultures.*— (Plate IV, Figs. 4, 7) 6.0–8.4 cm. diameter; white to tilleul-buff, vinaceous-buff, avellaneous and wood brown or cream-buff and chamois, the colour being pale and evenly distributed or limited to certain zones, either near the inoculum or at some distance from it; margin sharply defined; mat slightly raised, cottony in newest growth, becoming woolly, amorphous (i.e., individual fibres no longer evident), and, in some isolates, flattened around the inoculum; reverse unchanged; odour lacking in some isolates, strong and unpleasant in others. *4-weeks-old cultures.*— (Plate IV, Figs. 5, 8). Colours as described above with some isolates developing the deeper tones of honey yellow and tawny-olive; mat slightly raised, uniformly woolly. Two isolates produced small areas crust-like in texture and tawny-olive to Saccardo's umber in colour

(Plate IV, Fig. 8). No fruiting occurred on any of the isolates up to the end of six weeks; reverse unchanged; odour no longer perceptible in any isolates.

Gallic and tannic acid media.—Strong diffusion zones are produced on both these media, with mats 24–45 mm. diameter after 7 days. Hence the fungus goes into Group 7 of Davidson, Campbell, and Blaisdell's scheme (2).

B. *Microscopic Characters*

Advancing zone.—Hyphae (Fig. 12) hyaline, thin-walled, contents staining in phloxine, with simple septa, branched, the branching frequently occurring immediately below a septum, 2.2–6.0 μ diameter. *Aerial mycelium.*—*(a)* hyphae as in advancing zone; *(b)* hyphae (Fig. 13) yellow to brown in potassium hydroxide solution, walls slightly thickened, frequently septate, branched, 2.2–4.5 μ diameter, usually ending in setal hyphae; *(c)* setal hyphae numerous in all parts of mycelial mat, slender, tapering to a point, with walls thick and dark brown in potassium hydroxide, 4.5–6.0 (–7.5) μ diameter, up to 350 μ long (Fig. 14; Plate IV, Fig. 2). *Submerged mycelium.*—*(a)* hyphae as in advancing zone; *(b)* crystals numerous, octahedral.

Poria Weirii from Thuja

A. *Macroscopic Characters*

1-week-old cultures.— (Plate IV, Fig. 9) 2.3–3.2 cm. diameter; white; margin sharply defined; slightly raised, cottony, loosely arranged, dotted with coarser fibres; reverse unchanged; odour none. *2-weeks-old cultures.*— (Plate IV, Fig. 10) 5.8–6.9 cm. diameter; white to cream-buff and chamois; margin sharply defined; outer part of mat raised, cottony, with radiating growth lines; inner part (near inoculum) flattened, appearing thinner, with farinaceous surface; reverse unchanged; odour strong and unpleasant. *4-weeks-old cultures.*— (Plate IV, Fig. 11) colours as described above, deepening to honey yellow and buckthorn brown, the colour being darkest in new growth, paler around inoculum; mat slightly raised in newest parts, cottony to plumose, becoming appressed, farinaceous around inoculum; reverse bleached; odour no longer perceptible.

Gallic and tannic acid media.—Strong diffusion zones with mats 20–40 mm. in diameter are produced on both media; hence the fungus goes into Group 7 of Davidson, Campbell, and Blaisdell's scheme (2) which is in accord with their observations.

B. *Microscopic Characters*

Advancing zone.—Hyphae hyaline, thin-walled, contents staining in phloxine, with simple septa, branched, 1.5–4.5 μ diameter. *Aerial mycelium.*— *(a)* hyphae as in advancing zone; *(b)* hyphae with slightly thickened walls, buff to brown in potassium hydroxide, with numerous conspicuous cross walls, branched, 3.0–6.0 μ diameter; *(c)* setal hyphae numerous in one isolate, but confined to certain isolated patches in the other, slender, tapering to a point, with walls thick and dark brown in potassium hydroxide, 3.0–5.0 μ diameter.

Submerged mycelium.—*(a)* hyphae as in advancing zone; *(b)* crystals numerous, octahedral.

A comparison of cultures of the root-rot organism and of *Poria Weirii* shows that they are similar in rates of growth, character of margin, general appearance of mycelial mat, production of minute dark brown resinous masses against the glass in old cultures, either in Petri dishes or culture tubes, reactions on media containing gallic and tannic acid, and in their microscopic characters. Cultures of *Poria Weirii* from *Thuja plicata* differ from those of the root-rot organism in their colour, which is a deeper yellow to brown rather than the paler avellaneous tones present in most isolates of the latter. This difference in colour is related, apparently, to the greater number of yellow-brown hyphae present in the *Poria Weirii* isolates. On the other hand, setal hyphae are less abundant in *Poria Weirii*, being sparsely distributed in most preparations, whereas in the root-rot organism they are abundant and conspicuous in every mount (Plate IV, Fig. 2) and are noticeable when cultures are examined with a hand lens. Identical structures occur in the isolates of the root-rot fungus and *Poria Weirii*, and the differences in the relative distribution of these structures account for the variations observed. It should be mentioned that the description of *Poria Weirii* is based on only two isolates, and that a greater range of variation might have been encountered had more cultures been available for study.

In spite of the differences recorded above, the comparison of cultures of the root-rot organism from *Pseudotsuga taxifolia* and *Tsuga heterophylla* with those of *Poria Weirii* from *Thuja plicata* has led to the conclusion that the root-rot organism is *Poria Weirii* or a form of it, thereby corroborating the identification based on a study of the decay and sporophores.

Armillaria Root-Rot in *Pseudotsuga*

This disease has caused appreciable loss in young Douglas fir at the Cowichan Lake Forest Experiment Station. Infected trees were distributed over the area on both good and poor sites but whether any correlation exists between the site and the intensity of the disease is not known. *A. mellea* was also found as far north as Campbell River on Vancouver Island and in the Fraser Valley on the mainland. Observations made to date suggest that it may be more prevalent in the Fraser Valley and north of Nanaimo on Vancouver Island than in the Cowichan Lake region.

In young Douglas fir stands, root-rots caused by both *Armillaria mellea* and *Poria Weirii* may be responsible for the stunting of leaves and twigs, discoloration of the crown, and the death of trees either singly, or in groups that are roughly circular in outline. The causal organism is readily determined in the presence of sporophores or of the advanced stage of the decay. Clumps of the honey-coloured mushroom, *A. mellea*, may be found at the base of an infected tree, or the resupinate brown, pored fruit-body of *P. Weirii* on the crown or trunk. The advanced decay caused by *A. mellea* in which "the wood becomes light yellow or white in colour, soft and spongy, often

stringy in conifers, and marked by numerous black zone lines" bears little resemblance to the pitted, laminated rot of *P. Weirii.* In the absence of sporophores or advanced decay *A. mellea* may be recognized because:

(a) it turns the needles pale yellowish to yellowish-brown colour instead of reddish-brown,

(b) an abnormal resin flow is commonly found at the basal region of infected trees. "On occasion this flow is so great that the litter surrounding the root collar becomes compacted into a hard crust,"

(c) veined white mycelial fans are abundant between the bark and wood of infected trees and "constitute one of the most reliable signs of the disease,"

(d) dark brown or black rhizomorphic strands may be present in the cambium, on the surface of diseased roots, and free in the soil,

(e) in the early stages of decay or in case of doubt cultures of the organism are readily obtained and are definitely diagnostic. Those of *A. mellea* are slow growing, develop branched, white rhizomorphs in the agar and a purplish-brown resinous surface growth which would never be confused with the yellow and buff cottony mycelial mat of *P. Weirii.*

Hence, although either of these root-rots of Douglas fir may cause a reduction of the current season's growth, discoloration of the foliage, and the death of the tree they may be distinguished by their sporophores, by the presence or absence of an abnormal resin flow, mycelial fans beneath the bark, and rhizomorphs, by the type of advanced decay, and by the character of the mycelium produced in culture.

Acknowledgments

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FROZEN STORAGE OF POULTRY

IV. FURTHER OBSERVATIONS ON SURFACE DRYING AND PEROXIDE OXYGEN FORMATION[1]

By W. H. Cook[2] and W. H. White[2]

Abstract

A package constructed from moisture resistant material, capable of being ventilated during chilled storage, and sealed to prevent surface drying during frozen storage, is described. Results are presented to demonstrate the ability of this package to maintain the desired humidity conditions. Jacketing a room to separate the cooling coils from the space occupied by the product does not prevent surface drying of boxed goods, presumably because of the absorption of moisture by the boxes. Delays between slaughter and freezing accelerate the development of rancidity in the fat of poultry during subsequent frozen storage, as indicated by the formation of peroxide oxygen. The free fatty acid content is not seriously affected unless the conditions prior to freezing enhance microbial development.

Introduction

It has been shown in earlier papers of this series (1, 2, 3) that surface drying, causing a loss of bloom and development of freezer burn, was the first type of deterioration to occur in poultry during frozen storage. It was also found that conditions favouring surface drying also promoted the development of rancidity in the fat. These results suggested the present studies on methods of packaging for minimizing surface drying, and the effect of delays between slaughter and freezing on the development of rancidity.

The results of previous investigations showed that surface drying could be minimized by lining the boxes with reasonably moisture-resistant stocks, such as waxed paper, provided the folds and joints were adequately sealed. Since adequate sealing of the liners used in wooden poultry boxes is commercially impracticable, other types of packages were studied. One disadvantage of a sealed package is that it maintains a high humidity within the package under all conditions, and during chilled (unfrozen) storage such a condition enhances microbial growth. As a certain proportion of market poultry is held in the chilled state for immediate domestic consumption there is an obvious need for a package that can be readily ventilated or sealed in accordance with trade requirements.

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Packaging Experiments

Description of Packages

Initial experiments were undertaken with several standard types of corrugated cartons. Those having telescoping covers proved to be best from the standpoint of packing, storing, and sealing. Commercial trials indicated that the strength of such a package was generally satisfactory for a six-bird size. Standard 12-bird packages were also used experimentally, and the use of heavy corrugated stocks and containers of suitable design would appear to make this size entirely practicable for net weights up to 50 or 60 lb.

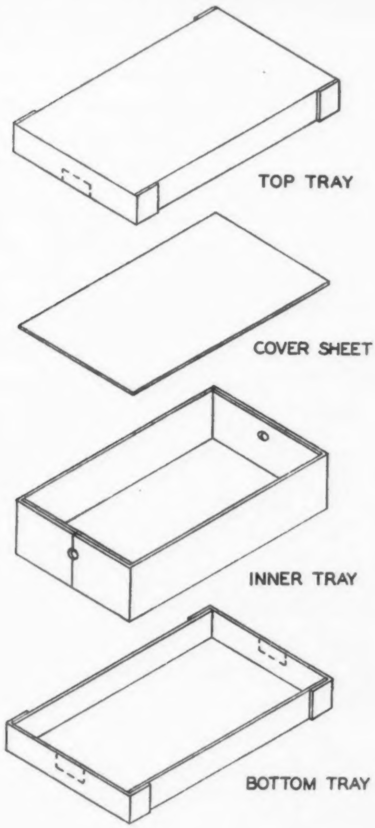
Cartons of this type must be rendered moisture-resistant. This was accomplished by various methods, including the application of wax or aluminium foil on one or both sides of the carton. Although the foil has many desirable features, the results of these preliminary tests indicated that the application of a sufficiently heavy coating of wax to produce a glossy surface on the inside was adequate for protecting the product. For commercial use the application of wax to the outer surface would also seem desirable to protect the package against condensate and other contact with moisture. All subsequent tests were conducted with both inside and outside surfaces waxed. No liners were used.

Although the ordinary type of full-telescoping carton was easier to seal than the liners in wooden boxes, it was still found difficult to obtain an effective seal in routine practice. This led to the design of the half-telescoping carton shown in Fig. 1, which proved to be comparatively easy to seal, and also facilitated storage of the product in either a "ventilated" or sealed condition. In this package the full size inner tray fits into another tray of half the height, and is covered by a similar half-height tray. These two cover members meet along the medial line of the container, and can be effectively sealed with a moisture-resistant adhesive tape. This construction also provides a double bottom to strengthen the package. If necessary, the carton can be strapped or wired before storage or transport.

The necessary ventilation during chilled storage was obtained by providing a hole in each end of the inner tray just above the joint of the two outer members. By suitably stamping the telescoping cover opposite these holes it was possible to provide a flap that could be broken open to expose the holes when ventilation was desired, or sealed beneath the tape to provide a moisture-tight package. Previous tests demonstrated that a relative humidity range of 85 to 90% was obtained during chilled storage when the openings in the inner tray were $\frac{1}{2}$, $\frac{3}{4}$, and 1 in. for boxes designed to contain about 25, 40, and 60 lb. of poultry respectively. Liners were not used in these packages since they were unnecessary and might obstruct the openings.

Results

Semi-commercial scale tests were conducted with the new design of package in both chilled and frozen storage. The relative humidity inside the package was taken as the criterion of proper ventilation in the chilled state, while the



EXPLODED ASSEMBLY

FIG. 1. *N.R.C. design of corrugated carton used to facilitate ventilation or sealing.*

proportion of the surface area affected by freezer burn after 27 to 32 weeks' storage at $-12°$ C. was used as a measure of its value for protecting the frozen product against drying.

The chilled storage tests were of 30 days duration at 0° C. During this period two relative humidity measurements were made on each of the experimental boxes using the special hair hygrometer referred to in earlier work (1). Observations were made on both ventilated and sealed packages of the type described earlier, and also on a few of the older types of containers. The results in Table I show that the ventilated N.R.C. type maintained relative humidities between 85 and 90%, which is considered satisfactory. This package in the sealed form, and all the other containers tested, maintained

TABLE I

RELATIVE HUMIDITY IN POULTRY BOXES DURING 30 DAYS' STORAGE AT 0° C.

Type of box	No. boxes in test	Range of size (net wt. poultry, lb.)	Relative humidity inside boxes during storage		
			Max.	Min.	Av.
N.R.C.—ventilated	5	19–75	90	84	86
N.R.C.—sealed	5	22–74	100	98	99
Ordinary telescoping carton—unsealed	1	28	—	—	98
Wooden box with unsealed moisture-resistant liner	2	42–50	98	100	99

humidities approaching saturation, which is clearly too high for satisfactory storage in the chilled state.

The extent of surface drying in the various containers stored in the frozen state is evident from the results presented in Table II. The average value of 2% indicates that the new containers give adequate protection from surface drying. For the most part the small freezer-burnt areas occurred only on certain birds that had been forced in close contact with lightly waxed regions of the cartons. Experienced inspectors examining these boxes reported no evident deterioration, and classed the bloom as "good" or "excellent".

Although only a limited number of other types of boxes were available for comparison, the results are in complete agreement with those obtained in earlier preliminary experiments. An ordinary waxed but unsealed telescoping

TABLE II

SURFACE DRYING DURING STORAGE IN FROZEN STATE

Type of box	No. boxes in test	Storage conditions	Proportion of surface area affected by drying			Remarks
			Max., %	Min., %	Av., %	
N.R.C.—sealed	8	27 weeks at −12° C. 65% R.H.	8	1	2	
N.R.C.—sealed	11	32 weeks at −12° C. 65% R.H.	3	1	2	Figures exclude one damaged box showing 10% F.B.
Ordinary telescoping carton—unsealed	2	32 weeks at −12° C. 65% R.H.	30	3	14	
Wooden box with unsealed moisture-resistant liner	1	32 weeks at −12° C. 65% R.H.	—	—	14	
Wooden box with sealed moisture-resistant liner	2	27 weeks at −12° C. 65% R.H.	3	1	2	

carton, and the usual wooden box with unsealed liner both showed about 14% of the area of the product affected by freezer burn. Inspectors reported deterioration in these boxes. Sealing the waxed paper liner in the wooden boxes reduced the affected area to 2%, in agreement with earlier results (1).

One of the recent developments for preventing drying and shrinkage of individually wrapped birds during storage is the use of thin transparent latex bags. Ten birds were sealed in these bags and exposed, without further protection, for a period of 43 weeks to the conditions described earlier. At the end of the storage period there was no evidence of drying, and the loss in weight was less than 1%.

Experiments in Jacketed Spaces

Primarily, a moisture-resistant packaging provides a vapour barrier between the product and the cooling coils, the regions of maximum and minimum vapour pressure respectively. The introduction of this vapour barrier in the same relative location, but as part of the room rather than as part of the package, might prove equally effective and less costly in the prevention of drying. The use of a jacketed room, as suggested by Huntsman (4), with the cooling coils placed between the jacket and the insulated wall, appears to meet these requirements. Although a cold store of this type would doubtless reduce desiccation, it might not be as effective as moisture-resistant packaging, since there is some evidence (5) that packages such as wooden boxes may themselves absorb considerable moisture from the air at relative humidities approaching saturation. In these circumstances the cooling coils may not be the only agency responsible for drying, and consequently their isolation from the space occupied by the product may be only partially effective in reducing desiccation.

This possibility was examined by placing two boxes of poultry in each of two gas-tight steel tanks to represent jacketed spaces. These were of sufficient size to contain two boxes of poultry in $\frac{2}{3}$ to $\frac{3}{4}$ of their volume. Approximately 20 lb. of ice was placed in the bottom of one of the tanks, in order to provide a source of water vapour, other than the product, for the maintenance of a high relative humidity. The other tank contained only the boxed product. In all instances the poultry was packed in wooden boxes with moisture-resistant unsealed liners. The tanks were stored at a temperature of from -12 to $-15°$ C. for a period of 87 weeks before being opened for examination. This prolonged storage period was used to exaggerate any surface desiccation that might have occurred.

Results showing the condition of the poultry in the two tanks at the end of the storage period are given in Table III. Serious deterioration of the product had occurred in the tank without ice, while that in the tank containing ice did not show marked injury. Although this product was stored for an excessively long period, the results nevertheless demonstrate that the absorption of moisture by the package may cause serious surface desiccation. In these circumstances it is evident that goods packed in containers capable

TABLE III

SURFACE DRYING FOLLOWING 87 WEEKS' STORAGE AT −12 TO −15° C. IN GAS-TIGHT TANKS WITH AND WITHOUT ICE

Storage conditions	Surface area affected by desiccation, %	Bloom
In tank without ice	20–25	Poor
	10–15	Poor
In tank with ice	0–5	Good
	0–5	Excellent

of absorbing moisture cannot be stored successfully in a jacketed room unless a high humidity is maintained by some agency other than the stored product.

Formation of Peroxide Oxygen and Free Fatty Acids

The results of a previous investigation on the frozen storage of poultry showed that the fat was relatively resistant to oxidative and hydrolytic changes (3). Although surface desiccation accelerated peroxide oxygen formation, it was found that, even under conditions favouring severe drying, the peroxide oxygen content seldom exceeded 8.0 ml. of 0.002 *N* sodium thiosulphate after a storage period of 25 months at −13.5° C. It was concluded that the extent of the decomposition of the fat should seldom effect serious deterioration in the flavour of poultry which was promptly precooled and stored at suitable temperatures in the frozen state for normal storage periods.

In commercial practice, delays in cooling or freezing may unavoidably occur, and if sufficiently prolonged may result in a considerable acceleration of the decomposition of the fat. Although such changes may not be evident immediately because of the nature of the induction period characteristic of the development of rancidity, the fat may become rancid quite rapidly during a subsequent period of frozen storage. The material available from the packaging experiments described previously permitted some preliminary observations on this problem.

Peroxide oxygen and free fatty acid determinations were made by methods previously described (3), on the subcutaneous and skin fat of one or two birds taken at random from each of a number of the boxes at the end of the period of frozen storage. This material represented poultry that had been precooled and packed in a commercial plant, and which had been held at temperatures of approximately 0° C. for periods of one week and five to six weeks between slaughter and freezing. Since none of the boxes from which the samples were taken suffered evident deterioration from drying, the accelerating action of surface desiccation on peroxide oxygen formation was excluded.

The peroxide oxygen and free fatty acid contents of the fat and the corresponding storage conditions are shown in Table IV. Poultry held for one week at 0° C., followed by frozen storage at −12° C. for 32 weeks, yielded peroxide oxygen values approximately twice as large as those previously obtained for poultry stored for much longer periods (3). This suggests that delays before precooling or freezing were responsible for the greater deterioration. The free fatty acid contents for this group of poultry were low and approximately normal.

TABLE IV

PEROXIDE OXYGEN AND FREE FATTY ACID CONTENT OF POULTRY FAT FOLLOWING VARIOUS STORAGE TREATMENTS

Storage conditions	Peroxide oxygen (as ml. 0.002*N* $Na_2S_2O_3$ per gm.)	Free fatty acid as % oleic acid
Precooled commercially, stored one week at 0° C., and 32 weeks at −12° C.	4.0	0.57
	2.7	0.59
	3.0	0.67
	0.8	0.54
	4.9	0.65
	1.7	0.53
Precooled commercially, stored 5 to 6 weeks at 0° C., and 27 weeks at −12° C.	6.3	5.3
	8.8	19.9
	11.1	15.2
	5.1	31.4
	18.4	12.9
Precooled commercially, frozen and stored in a gas-tight tank containing ice for 87 weeks at −12 to −15° C.	9.3	0.95
	6.3	0.60
	6.4	0.88
	11.7	0.89

The next series of samples studied were obtained for poultry stored for five to six weeks at 0° C., followed by storage for 27 weeks at −12° C. Under these conditions the peroxide oxygen values had increased to levels at which the fat would be considered rancid. In addition the free fatty acid content was high, and would undoubtedly exert a deleterious effect on flavour. The excess free fatty acid formation may be attributable to excessive microbial activity during storage at 0° C. These results show conclusively that the product should be precooled and frozen promptly after slaughter in proper storage practice.

It is evident that there is considerable variation in the peroxide content of the fat of birds treated similarly. This indicates a difference in the susceptibility of the fat of different birds to oxidation, and is in agreement with previous findings (3). Doubtless the breeding and feeding of the poultry affects the susceptibility of the fat to oxidation.

The last section of Table IV gives the results of the analysis of the fat of two birds taken from each of the two boxes stored in the gas-tight tank con-

taining ice (see Table III). The peroxide oxygen values were generally higher than those observed previously (3). This may be due to greater delays in precooling and freezing the present material, or to a greater susceptibility of the fats of these birds to oxidation. Nevertheless it is evident that poultry fat may become slightly or definitely rancid under storage conditions that prevent surface drying. Rancidity development is therefore one of the factors limiting the storage life of poultry stored at $-12°$ C. even when surface drying is prevented. These birds were stored for an excessive period, however, and under commercial storage practice, surface drying, which is directly detrimental to quality, and indirectly accelerates oxidative changes, is likely to be the primary factor limiting the storage life.

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